

I. Water treatment

1. Water system

a) Sources of water

- *Rain water*: from roofs of houses, and prepared catchments.
- *Ground water*: from natural springs, wells and bore holes, infiltration galleries, river side radial collector wells.
- *Surface water*: from rivers by continuous draft, from river diversions, from reservoir storage, from direct intake from natural lakes.
- *Water obtained by reclamation*: Desalination and Re-use of treated waste water.

b) Ground water: wells

• Terms

- ◆ **Storage coefficient (S)**: Storage coefficient is defined as the volume of water that an (confined) aquifer releases from or takes into storage *per unit surface area* of aquifer *per unit change in the component of head* normal to that surface. Its value can be determined by pumping test on wells penetrating fully into confined aquifer.

- Storage coefficient for an *unconfined aquifer* corresponds to its *specific yield*. As the water table is lowered by one meter height of the vertical column of unit area drains freely under gravity.

- ◆ **Transmissibility (T)**: Coefficient of transmissibility is defined as the rate of flow of water through a vertical strip of aquifer of unit width and extending the full saturation height under unit hydraulic gradient, at a temperature of 60° F.

$$T = B \times k$$

- Also, it is rate of flow per unit width for a unit hydraulic gradient.

- ◆ **Specific capacity** of a well is the measure of the effectiveness of the well, and is defined as the *yield of the well per unit drawdown*. It decreases with increase in discharge.

$$\text{specific capacity} = \frac{Q}{s}$$

- ◆ Darcy's Law

$$Q = k \cdot i \cdot A$$

- Valid when $Re = \frac{\rho v d}{\mu} \leq 1$
- For the GW flow occurring in nature, the law is generally within its validity limits. But in rock aquifers, in unconsolidated aquifers with steep hydraulic gradients, Darcy's law may not be applicable. Also, the flow in immediate vicinity of wells have steep hydraulic gradient and Darcy's law is not applicable there.

- ◆ Specific Yield

$$Y_s = \frac{\text{amount drained by gravity}}{\text{amount of medium drained}}$$

- ◆ Specific Retention

$$Y_r = \frac{\text{amount retained against gravity}}{\text{amount of medium drained}}$$

- ◆ Porosity $n = Y_r + Y_s$

• Geological Formations

- ◆ *Aquifer*: these are the type of geological formation which are both porous and permeable hence sufficient discharge can be obtained through them. Example: fine sand, coarse silt.
 - Unconfined aquifer: also called as *water-table aquifer* is the one in which a water table serves as the upper surface of the zone of saturation
 - Confined aquifer or artesian aquifer is the one in which ground water is confined under pressure greater than atmospheric by overlying, impermeable strata.

- Perched aquifer is a special type of unconfined aquifer, occurs where a ground water body is separated from the main ground water by a relatively impermeable stratum of small aerial extent.
- ◆ *Aquiclude*: these are the type of formations which are highly porous but impermeable hence water cannot be drained through it. Example: clay
- ◆ *Aquitard*: these are the type of geological formations, which are porous but less permeable hence water doesn't flow through them but instead it seeps. Example: sandy clay
- ◆ *Aquifuge*: these are type of geological formations which are neither porous nor permeable. Example: granite rocks
- Steady flow discharge
 - ◆ Discharge through:

Infiltration Gallery Discharge per unit length	$q = \frac{k(H^2 - h^2)}{2L}$
Well in Unconfined Aquifer Dupit equation	$Q = \frac{\pi k(H^2 - h^2)}{\ln \frac{R}{r}}$
Well in Confined Aquifer Thiem equation	$Q = \frac{2\pi bk(H - h)}{\ln \frac{R}{r}}$

*natural log is used in these equations

- Sichardt equation
 - ◆ $R(m) = 3000s\sqrt{k(m/s)}$ s- drawdown at well
- Well Interference
 - ◆ Two well

$$Q_1 = Q_2 = \frac{2\pi Bk(H - h)}{\ln \frac{R^2}{rB}}$$

B- c/c distance b/w wells

- ◆ Three well

$$Q_1 = Q_2 = Q_3 = \frac{2\pi Bk(H - h)}{\ln \frac{R^3}{rB^2}}$$

c) Open wells

- An open well is essentially of bigger diameter than of a tube well, and derives its water only from one pervious stratum. The economically feasible depth of an open well is limited to 30 meters below the ground surface. In a lined open well, the **entry of water is from the bottom** and not from the sides. They are classified as
 - ◆ Shallow well: nomenclature has nothing to do with actual depth of well. It penetrates the pervious stratum only.
 - ◆ Deep well: it is one which is supported on a *mota* layer and draws water from the hole bored in it.
- Yield of an open well can be found by following two tests.
 - ◆ Constant level pumping test

$$Q = A \times v$$

$$Q = A \times C \times h$$
 - Where, C- percolation intensity coefficient, h- depression head
 - ◆ Recuperation test: it is difficult to regulate a pump in such a way that constant level is maintained in the well, therefore recuperation test is done. The time taken for water to recuperate to normal level is noted.
 - Specific yield

$$\frac{K}{A} = \frac{1}{T} \ln \frac{h_1}{h_2}$$

$$Q = \left(\frac{K}{A}\right) AH = \frac{1}{T} \ln \frac{h_1}{h_2} AH$$

- H – maximum depression head for maximum discharge.

d) Unsteady flow

- Basic equation of unsteady flow in Confined aquifer

$$\diamond \frac{\partial^2 h}{\partial r^2} + \frac{1}{r} \frac{\partial h}{\partial r} = \frac{S}{T} \frac{\partial h}{\partial t}$$

- Integrating above gives

- ◆ Draw down in well

$$s = \frac{Q}{4\pi T} W(u)$$

- ◆ Well function

$$W(u) = \int_u^\infty \frac{e^{-u}}{u} du$$

- ◆ Where $u = \frac{r^2 S}{4Tt}$

e) Intake structures

- Intakes are structures used for admitting water from the surface sources and conveying it further to the treatment plant. Generally, an intake is a masonry or concrete structure with an aim of providing relatively clean water free from pollution.
- The site should be so selected that it may admit water even under worst condition of flow in the river.
- It should be nearer to the treatment work and should be so located that it admits relatively pure water free from mud, sand and other floating materials.
- It should be constructed well upstream of point of discharge of sewage and industrial waste.

2. Water Demand and Quantity

a) Introduction

- Before designing a proper water works project, it is essential to determine the quantity of water that is required daily. This involves determination of Population and rate of demand.
- Design period
 - ◆ Generally, water supply projects are designed for a design period of 20 to 40 years, after their completion. Different segments of water treatment and distribution system may be designed for different periods of time.

b) Water demand

- Total water requirements may be divided into following five categories:
 - ◆ Residential or domestic use: (drinking, cooking, bathing, washing of clothes, utensils and house, and flushing of water closets.) 135l/day (IS 1172)
 - ◆ Institutional use: Hospitals 450-340 per bed, Hotels 180 per bed, hostels 135, restaurant 70
 - ◆ Public or civic use: (road washing, sanitation, public parks, firefighting)
 - Fire Demand 🔥🔥🔥
 - Though the total demand of water for extinguishing fire is very small, the rate of consumption is very high

Can be taken as	GOI	National board of fire underwriters	Kuichling's formula
1 lcd	$Q = 100\sqrt{P}$ kilo liter/day P is in thousands	$Q = 4637\sqrt{P}(1 - 0.01\sqrt{P})$ In l/min	$Q = 3182\sqrt{P}$ l/min

- ◆ Industrial use: paper industry has largest water requirement, then steel, distillery and fertilizer.
- ◆ Water system losses: leaks and over-flow from service reservoirs, mains, public taps.

c) Variations in rate of demand

- The average daily per capita consumption is obtained by dividing the quantity of water supplied during the year

Maximum	Demand
Daily	= $1.8 \times$ Annual average daily demand
Hourly	= $1.5 \times$ average hourly demand of max day
Hourly	= $2.7 \times$ annual avg. hourly demand

- Fluctuations in hourly demand is called peak factor, also depends on population

Population	Peak factor
< 50,000	3
50,000 – 2,00,000	2.5
> 2,00,000	2

- Coincident demand = maximum daily demand + fire demand
- Design is done for max (CD, max hourly demand)

d) Effect of variation in consumption of design

Filter and Pumps are designed for	1.5 times ADD = maximum daily demand
Distribution main	Maximum Hourly demand = 2.7 times ADD
Sedimentation tank and water reservoir	ADD

e) Population Forecasting

Arithmetic Increase	It is the simplest method, gives lower results. Increases in population is assumed constant.	$P_n = P_0 + n\bar{x}$ \bar{x} is average increment for a decade.
Geometric Increase	In this method, it is assumed that the percentage increase in population from decade to decade is constant. This method gives higher results.	$P_n = P_0(1 + r_g)^n$ ➤ $r_g = \frac{r_1 + r_2 + \dots}{n}$ ➤ $r_g = (r_1 r_2 \dots)^{1/n}$ recommended
Incremental Increase	This method combines both the above methods. The actual increase in each decade is first found, then the increment in each decade is found. Average increment of the increases is found.	$P_n = P_0 + n\bar{x} + \frac{n(n+1)\bar{y}}{2}$ \bar{x} Average increase per decade \bar{y} average incremental increase
Decreasing rate of growth	An average decrease in % rate of growth is considered.	Find % rate, and decrease in % r , find $\% \Delta r$ average and calculate new $r = \% r - \Delta \% r$

Out of all the above methods geometric increase method gives the highest value of population forecasted. Hence is *suitable to be used for young city*. Arithmetic increase method gives the lowest value of population forecasted hence is suitable to be used for very old city.

f) Logistic Curve Analysis

- It is found that the rate of increase of population never remains constant, but varies. The population of a city will grow until it reaches a saturation population which is established by limit of economic opportunity.
- Basic equation

$$\ln\left(\frac{P_s - P}{P}\right) - \ln\left(\frac{P_s - P_0}{P_0}\right) = -KP_s t$$

- Population at any time

$$P = \frac{P_s}{1 + m e^{nt'}}$$

- Time t' is taken from beginning ie. From P_0
- For given three value of population at equal interval we can fit logistic curve to find value at any other point. Time is taken from initial point.
- Saturation population (P_s)

$$P_s = \frac{2P_o P_1 P_2 - P_1^2 (P_o + P_2)}{P_o P_2 - P_1^2}$$

$$m = \frac{P_s - P_o}{P_o}$$

$$n = \frac{1}{t_1} \ln \left\{ \frac{P_o (P_s - P_1)}{P_1 (P_s - P_o)} \right\}$$

3. Quality of water

Parameters	Measurement	Acceptable limit	Rejection limit
S.S.	Gravimetric technique	500 mg/l	2000mg/l
Turbidity	<i>Turbidity rod</i> : used to measuring turbidity in field. Aluminium rod (20.3cm) with platinum needle is used.	1 NTU	10 NTU
	<i>Jackson's turbidimeter</i> it is a laboratory apparatus, used when turbidity is > 25ppm . It is height of water column, at which image of flame of a standard candle ceases to be seen. Longer is the light path the lower is turbidity.		
	<i>Baylis Turbidimeter</i> This is very accurate instrument and is preferred when turbidity of sample is less than 5 units. (BTU)		
	<i>Nephelometer</i> these are modern commercial turbidimeters in which light intensity is measured at right angles to the incident ray in contrast to conventional turbidimeters. (since Formazine polymer is used as reference standard suspension it is also called FTU = NTU)		
Color	<i>Tintometer (cobalt scale)</i> : one unit of colour is that produced by one milligram of <i>platinum cobalt</i> in one liter of distilled water.)	5 TCU	25 TCU
Taste and odor	<i>Osmoscope (Threshold Odor Number)</i> – it is numerically equal to the volume of sample of water in cubic centimeters required to be added to 100cc of odour free fresh water when the mixture just starts giving the typical smell in the diluted sample.) $TON = \frac{A+B}{A}$	1 TON	3 TON
TDS	Di ionic water tester		
Alkalinity	CO ₃₂₋ HCO ₃₋ OH- 0.02N H ₂ SO ₄ is used as titrant V ml = Vmg of CaCO ₃ Alkalinity. At pH 8.3 carbonate and caustic is removed and converts to Bicarbonate (phenolphthalein, pink-colorless) At pH 4.5 all bicarbonates are neutralized (methyl orange to yellow)	200 mg/l	600mg/l
pH -log[H ₊]	pH + pOH = 14 measured with <i>potentiometer</i> Acidic water causes tuberculation while alkaline water causes incrustation .	7-8.5	<6.5;>9.2
Hardness	Hardness is due to presence of multivalent cations. Titration with Versenate solution, 0.01M EDTA (<i>Di-Ethylene diamine tetracetic acid</i>) using EBT (<i>Erio chrome black T</i>) as indicator (Blue black → wine red) Carbonate Hardness = Alkalinity, if Na is absent Alkalinity > CH, TH=CH CH = min of (TH, Alkalinity)	200mg/l	600mg/l
Chloride	Chlorides are estimated by titration with standard <i>silver nitrate</i> AgNO ₃ solution using potassium chromate K ₂ CrO ₄ as indicator. Mohr's method , Yellow (AgCl) to Reddish Brown (Ag₂CrO₄)	200mg/l	1000mg/l

Nitrogen	Free Ammonia	Their occurrence indicates recent pollution from direct inclusion of organic matter from excrement. Estimated by distillation of mildly alkalized water and measured from coloration produced with <i>Nessler's reagent</i>	0.15 mg/l	
	Organic Ammonia (albuminoid)	It is normally derived from animal and plant life. Its presence gives an indication of pollution in water supply. Before decomposition has started Boiling + KMnO_4 liberates ammonia gas OA+FA= Kjeldahl Ammonia	0.3 mg/l	
	Nitrite	It indicates <i>partly decomposition</i> of organic matter Sulphonic acid + Naphthamine gives red colour which is matched with standard series.	Highly dangerous '0'	
	Nitrate	It indicates the <i>final stage in oxidation</i> . Old pollution Phenol-di-sulphonic acid + Potassium Hydroxide	45mg/l *-blue baby	
Fluoride	Estimated calorimetrically by developing a colour with <i>Zirconium alizarin</i> reagent. In small concentration <i>1.2ppm</i> prevents dental caries of children. Higher concentration cause Mottled enamel (1.5-2mg/l) Bone fluorosis (5mg/l)		1 mg/l	1.5 mg/l
Metals	<p>Toxic:</p> <p>As (0.1mg/l): chronic arsenic poisoning can be quite disabling and difficult to diagnose.</p> <p>Pb (0.05mg/l): causes <u>cumulative poisoning</u>, measured using Sulphuric acid, it can be removed from water in ion exchange equipment using activated alumina or bone char.</p> <p>B (0.3-1.5mg/l): ingestion of large amounts of boron can affect <u>central nervous system</u>.</p> <p>Ba (0.7mg/l): Barium can have <u>serious toxic effects on heart</u>, blood vessels, and nerves.</p> <p>Cd (0.003mg/l): is highly toxic, careless discharge from electroplating and galvanizing.</p> <p>Cr (0.05mg/l): is carcinogenic above this limit</p> <p>Cy (0.05mg/l): toxic</p> <p>Hg (0.001mg/l): toxic</p>			
	<p>Nontoxic:</p> <p>Ca, Zn, K, Na atomic absorption spectroscopy,</p> <p>Fe: (0.1mg/l, 1mg/l) Calorimetric, imparts hardness, bad tastes, discoloration of clothes and plumbing fixtures and incrustation in water mains.</p> <p>Mn: (0.05mg/l, 0.5mg/l) titration and colour matching, imparts brownish or purplish colour to water and laundered goods, stains plumbing fixtures. It also impairs tastes of coffee and tea.</p> <p>I: if present in small concentration (1mg/l) is helpful to humans in keeping away <i>Goiter</i></p> <p>Cu: (0.05mg/l, 1.5mg/l) Astringent taste, discoloration and corrosion of pipes fittings and utensils. laxative effect, lungs and respiratory problem.</p>			
Phenols	Water receives phenol from trade wastes, washing from tarmac road, gas liquors and creosoted surfaces. Trace phenol concentration of order of .001ppm can impart an objectionable taste to a water following marginal chlorination. The removal of phenolic taste from a water supply offers a serious challenge at the treatment plant.			
O ₂	Modified Wrinkler test: Oxygen in the water sample oxidizes iodide ion (I ⁻) to iodine (I ₂) Quantitatively the amount of iodine generated is then determined by titration with a standard thiosulfate (S ₂ O ₃ ²⁻) solution. The endpoint is determined by using starch as a visual indicator.		If DO is absent White ppt If DO is present Red ppt	

At the time of sampling, dissolved oxygen is fixed by the addition of Mn(II) under basic conditions, resulting in a brown precipitate, manganic hydroxide (MnO(OH) ₂). Prior to analysis, the sample is acidified to pH 1.0-2.5. This causes the precipitated hydroxides to dissolve, liberating Mn(III) ions.		
MnSO ₄ + NaOH+KI	⇒ MnO ₂ (red ppt)	⇒ H ₂ SO ₄
	⇒ Starch indicator (blue)	⇒ Na ₂ S ₂ O ₃ titrate
		⇒ colourless

f) Thermal stratification

- It is a term which is applied to the variation in temperature of the impounded water with depth. Entire depth can be divided into three zones.
 - ◆ **Epilimnion**: this is the top zone, water is of good quality, having high dissolved oxygen.
 - ◆ **Mesolimnion**: it is a zone 3 to 6m deep, having rapidly changing temperature at the rate of 1°C per meter. There is oxygen depletion due to microbial activity and there is no opportunity of reaeration, so anaerobic conditions set in, with increases in iron carbon dioxide, manganese, H₂S, taste and odour.
 - ◆ **Hypolimnion**: This is the *bottom most zone* which is cold. It has practically no dissolved oxygen. It has very high dissolved iron and manganese. Anaerobic condition exists in this zone, also there is an increase in CO₂ and decrease in pH

g) Alkalinity

- It is defined as acid absorbing property of water. The major acid absorbing constituents that we typically deal with are hydroxides (OH⁻), bicarbonates (HCO₃⁻), carbonates (CO₃²⁻) ions.
 - ◆ **M alkalinity**: The M-alkalinity is a measure of the amount of acid it takes to drop the pH to approximately 4.3. This would directly measure the amount of any *bicarbonate, carbonate, and hydroxide* alkalinity present. Here, M refers to the pH indicator *methy orange* (endpoint 4.2 to 4.5); M alkalinity is what we usually call “alkalinity” or “general alkalinity” or “total alkalinity”.
 - ◆ **P alkalinity**: The P-alkalinity is a measure of the amount of acid required to drop the pH to approximately 8.3. This would measure the amount of any carbonate or hydroxide alkalinity present. P refers to the pH indicator *phenolphthalein* (endpoint 8.2 to 8.3).
 - ◆ **Caustic alkalinity**: It is due to presence of OH⁻ ions. It is equal to = (2P – M)
- The total alkalinity in water consists of alkalinity caused by OH⁻, HCO₃⁻, CO₃²⁻ and a very little *negative alkalinity* is caused by H⁺

CO ₃ ²⁻	HCO ₃ ⁻	OH ⁻	H ⁺
$\frac{CO_3^{2-} \text{ mg/l}}{\text{Eq wt of } CO_3^{2-}} \times 50$	$\frac{HCO_3^- \text{ mg/l}}{\text{Eq wt of } HCO_3^-} \times 50$	$\frac{10^{-\text{pOH}} \times 17 \times 1000 \text{ mg/l}}{\text{Eq wt of } OH^-} \times 50$	$\frac{10^{-\text{pH}} \times 1 \times 1000 \text{ mg/l}}{\text{Eq wt of } H^+} \times 50$

h) Hardness

- Hardness in water is that characteristic which prevents the formation of sufficient leather or foam. It is usually caused by the presence of calcium and magnesium salts present in water.
- They are undesirable because they may lead to greater soap consumption, scaling of boilers causing corrosion and incrustation of pipes, making food tasteless.
- If bicarbonates and carbonates of calcium and magnesium are present in water, the water is rendered hard temporarily, as this hardness can be removed by boiling or by adding lime to the water. Such hardness is called *temporary hardness* or carbonate hardness.
- Sulphates, chlorides and nitrates of calcium or magnesium if present require special treatment for softening. Such hardness is known as *permanent hardness* or non-carbonate hardness.
- Measurement
 - ◆ It is measured as calcium carbonate equivalent of calcium and magnesium ions present in water and is expressed in mg/l.

- ◆ After determining the amounts of calcium and magnesium ions present in water by titrating with *versnate* solution (EDTA method), hardness in mg/l can be determined as:

$$TH = \left[\frac{Ca^{2+} mg/l}{eq\ wt\ of\ Ca^{2+}} \right] eq\ wt\ of\ CaCO_3 + \left[\frac{Mg^{2+}}{eq\ wt\ of\ Mg^{2+}} \right] eq\ wt\ of\ CaCO_3$$

- ◆ Carbonate hardness CH = $\min \left\{ \begin{array}{l} \text{Alkalinity} \\ \text{Total hardness} \end{array} \right.$
- ◆ Non-carbonate hardness NCH = total hardness – alkalinity

i) Microbiological examination of water

- This includes both bacteriological and biological examination. *Bacteriological examination* of a sample is aimed at determining its fitness for use for human consumption and for industries such as food processing and dairy. *Biological examination* is aimed at determining the presence of microscopic organisms, other than bacteria, such as algae, moulds or fungi, yeasts, protozoa, rotifers etc.
- Indicator organisms
 - ◆ Pathogenic bacteria and other organisms are usually difficult to detect in a water supply because of their small numbers.
 - ◆ The indirect evidence of presence of the pathogenic bacteria in water is obtained by testing the water for indicator organisms.
 - ◆ The faecal bacteria although harmless in their normal habitat, do indicate pollution if found in water and give warning that the water must be potentially dangerous.
 - ◆ The coliforms and E-coli are normally used as indicator organisms, since they are present in large numbers than pathogens. They lend themselves to numerical evaluation as well as qualitative distinction. They are also identifiable by relatively simple analytical procedures, providing information quickly and economically.
- Coliform index
 - ◆ The number of coliforms in a water sample is deduced from positive results obtained in fermentation tubes inoculated with portions of varying sizes. The result so obtained is approximate and this approximate or probable number is known as coliform index. For a single sample with only a few portions, the index is taken as the reciprocal of the smallest portion showing positive results.
- Most probable number (MPN)
 - ◆ MPN of coliform or E-coli is defined as the bacterial density, which if present in sample under examination, would more frequently than any other, have given the observed analytical result.
 - ◆ It is determined by applying laws of probabilities to the available test data. *Standard tables* are available to determine MPN of test results.
- Coliform test: two standard test techniques are available for the coliform group.
 - ◆ Multiple tube fermentation technique
 - It consists of following tests in three stages:
 - ◆ Presumptive test: positive test shows the presence of any member of the coliform group.
 - ◆ Confirmed test: it confirms the presence of coliform organisms.
 - ◆ Complete test: the formation of gas
 - ◆ Membrane filter technique: (MAINS)
 - It is relatively a recent development of field measurement of bacteria. The method permits field filtration of the water sample and shipment of filters to the laboratory on a preservative medium.
 - The method consists of filtering the sample of water through a filter membrane of uniform microscopic pores small enough to retain all the coliforms and other bacteria.

- This membrane is then put in contact with nutrients (M-endo) to promote the growth of coliform bacteria to grow into visible colonies that are then counted.
- The results are reported in number of organisms per 100ml of water.
- This method has a higher degree of precision than the multiple-tube fermentation test.

j) Water Borne Diseases

Bacterial Diseases	Typhoid fever, Paratyphoid fever, Cholera, Bacillary dysentery
Protozoal Diseases	Amoebiasis, Amoebic dysentery
Virus Diseases	polio viruses, coxsackie viruses, ECHO viruses, the viruses of infectious hepatitis, the adenoviruses and the reoviruses.
Helminthic (worm) Diseases	Schistosomiasis, swimmer's itch

4. Treatment of water

- a) **Screening:** it is the process of removal of heavy suspended particles from water. It is adopted generally for surface water treatment. Screens are placed at source at intake structure.
- Coarse screens: also called bar screen or trash rack.
 - ◆ Head loss $h_l = \frac{k}{2g} (v^2 - u^2)$
 - Fine screens: these are in the form of wire mesh. Under normal treatment conditions they are avoided as they get frequently choked requiring cleaning which increases operational cost.
- b) **Aeration:** the process in which water is brought in intimate contact with air, so as to allow absorption in order to carry out removal of foul gaseous impurities.
- It removes CO₂ and H₂S gases, organic matter, volatile liquids like phenol and humic acids, dissolved minerals (Fe, Mn)
 - It is adopted for treatment of water devoid of O₂ like ground water and water from lakes.
 - Methods of aeration
 - ◆ Spray nozzle
 - ◆ Tray tower
 - ◆ Cascade aerator
 - ◆ Diffused air method
- c) **Coagulation:**
- Efficiency of plain sedimentation is comparatively reduced if water consists of fine suspended particles. In this process certain chemicals (coagulants) **added in water to neutralize negative protective charges present on particles** resulting in increases opportunity of contact between particles and sticky precipitates form bigger particles which can get easily settled.
 - **Aluminium Sulphate** or *Alum*
 $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ (666gm)
 - ◆ It reacts with alkalinity present in water and leads to formation of sticky gelatinous precipitate, which attract fine suspended particles over its surface to make bigger particles which get settled easily.

$$\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O} + 3\text{Ca}(\text{HCO}_3)_2 \rightarrow 2\text{Al}(\text{OH})_3 \downarrow + 3\text{CaSO}_4 + 18\text{H}_2\text{O} + 6\text{CO}_2$$
 - ◆ Depending on the pH of the medium Al(OH)²⁺, Al(OH)¹⁺, Al(OH)₃ is formed.
 - Al(OH)²⁺, Al(OH)¹⁺ works by charge neutralization.
 - Al(OH)₃ works by sweep coagulation.
 - ◆ If alkalinity is not present in water naturally, it is induced artificially by addition of lime or soda ash.

$$\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O} + 3\text{Ca}(\text{OH})_2 \rightarrow 2\text{Al}(\text{OH})_3 + 3\text{CaSO}_4 + 18\text{H}_2\text{O}$$
 - ◆ As soon as Alum is added Alkalinity↓ decreases and turbidity↑ increases, permanent hardness↑ increases.

- ◆ Works best in high turbid and alkaline water (pH **6.5 to 8.5**)
 - ◆ It removes taste, colour, odour and microorganisms from water. Dose of alum depends upon turbidity and colour of water and is determined using jar test.
 - Copperas $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$
 - ◆ It is not used in colored water treatment; it is comparatively cheaper than alum. pH range 8.5 and above so always used in conjugation with lime.

$$\text{FeSO}_4 \cdot 7\text{H}_2\text{O} + \text{CaO} \rightarrow \text{Fe(OH)}_2 + \text{CaSO}_4 + 4\text{H}_2\text{O}$$
 - ◆ Molecular mass of copperas = $56 + 32 + (4 \times 16) + (7 \times 18) = 278 \text{ g/mole}$
 - Chlorinated copperas $\text{Fe(SO}_4)_3 + \text{FeCl}_3$
 - ◆ Works in wide pH range
 - Sodium aluminate $\text{Na}_2\text{Al}_2\text{SO}_4$
 - ◆ It reacts with calcium and magnesium present in water and forms sticky gelatinous precipitate of calcium and magnesium aluminate, which attracts fine suspended particle resulting in bigger suspended particle which settle easily.
 - ◆ It does not require any alkalinity to be present in water, moreover also removes hardness from water unlike other coagulants.
 - ◆ It is generally used in boiler feed water, and is costlier than alum.
 - Iron salts vs Aluminium salts
 - ◆ Iron salts are cheaper than Aluminium salts. It works in wide pH range. Iron flocks are heavier and form earlier than Aluminium flocks.
 - ◆ Alum is used for treatment of water supplies whereas **iron salts** are used in the treatment of **sewage**. Use of iron salts promotes growth of iron bacteria that causes pitting tuberculation in pipes.
 - ◆ Strict supervision is required for handling of iron salts, as their quality gets deteriorated due to storage over time.
 - Coagulant aids
 - ◆ Coagulation problems often occur because of slow settling precipitates or fragile flocs that are easily fragmented under hydraulic forces in basins and filters.
 - ◆ A **coagulant aid is a chemical added during coagulation to improve coagulation**; to build stronger, more settleable flocs; to overcome the effect of temperature drops that slow coagulation; to reduce the amount of coagulant needed; and to reduce the amount of sludge produced.
 - ◆ In drinking water treatment, polymers are extensively used as coagulant aids to build large floc prior to sedimentation and filtration. Other coagulant aids are activated silica, adsorbent-weighting agents, and oxidants.
- d) Fast mixing
- The timing of the addition of coagulants, has been found to be of great importance and is usually critical to clarification performance and filter performance. It is desirable to introduce the coagulants at points of high turbulence in the water in order to complete the coagulation reaction in as short time as possible – preferably within a period of several seconds. This is accomplished by **fast mixing**.
 - Types of mixers
 - ◆ **Mixing basins**: in this, mixing is induced by generating turbulence which is achieved by rapid changing direction of flow of water either in vertical or horizontal plane. (i) around and end type (ii) over and under type.
 - ◆ **Mechanical mixers**: In this, mixing is induced by vigorous agitation of coagulants into the water. Intensity of which is represented in terms of parameters *temporal mean velocity gradient* G that signifies that relative velocity between the particles located at a particular distance from each other.

$$G = \sqrt{\frac{P}{\mu V}}$$

- P - in watt μ - N-s/m² V - m³ G - s⁻¹
- Deep circular or square tanks are provided in this case with D: W 1:1 to 3:1, detention time of these tanks is in the range of **30 to 60 sec**. Temporal mean velocity gradient is greater than **$G \geq 300/\text{sec}$** .

◆ **DESIGN consideration**

- Velocity of tip $v_t = \omega r_{tip}$
 - $r_{tip} = r_{\text{center of paddle}} + \frac{\text{width of paddle}}{2}$
 - $\omega = \frac{2\pi N}{60}$
- Relative velocity

$$v_r = v_p - v_{\text{water}}$$

$$v_r = v_p - v_w = v_p(1 - k)$$

- In case of design, velocity of tip is taken to be on the safe side, for analysis or finding the power consumed, velocity of center of paddle is used.
- Power delivered

$$P = \frac{1}{2} C_D \rho A_p v_r^3$$

- $C_D = 1.8$ for paddles with flat blades
- A_p - area of paddles,

e) **Flocculation** (slow mixing)

- Neutralized particles are brought in immediate contact with each other and sticky precipitate to form bigger particles. In order to increase the opportunity of agglomeration **slow mixing** is induced.
- **Conjunction opportunity**: it signifies the number of collisions between particles.

$$G \times t_d = \frac{V}{Q} \sqrt{\frac{P}{\mu V}} = \frac{1}{Q} \sqrt{\frac{PV}{\mu}} = \frac{\text{Power induced flow}}{\text{Displacement flow}}$$

$G \uparrow t \downarrow =$ small dense flocs

$G \downarrow t \uparrow =$ large light flocs

- ◆ **Tapered flocculation**: As large dense flocks get easily settled, it is advantageous to vary the value of G along the length of flocculation tank, small dense flocks formed in initial section which combines with larger lighter flocks to give large dense flocks. G in tank is made to vary from 100/s in first stage to 50 to 60 /s in the second stage and then brought down to 20/s in third stage in the direction of flow.
- The desirable value of velocity gradient G in a flocculator vary from 20 to 75 /sec and Gt_d from $2 - 6 \times 10^4$ for aluminium coagulants and $1 - 1.5 \times 10^5$ for ferric coagulants.
- Detention period of less than 10 minutes should be avoided; the usual detention period varies from 10 to 30 minutes.

f) **Sedimentation**: it is the process of removal of suspended particles from water.

- Types of sedimentation tank
 - ◆ **Quiescent type**: also called fixed or fill and draw type. These are type of tank in which flow is completely stopped for 24 hrs. These are designed for treatment of maximum daily demand, detention time is 24 hrs., cleaning period is 6-12 hrs. sludge zone is provided for manual cleaning, one extra unit is provided as standby.
 - ◆ **Continuous flow type**: these are further classified as horizontal and vertical flow type.
- Settling velocity

$$v_s = \sqrt{\frac{4(G-1)gd}{3C_D}}$$

- ◆ Drag coefficient C_D depends on Reynolds number

$R_e < 0.5$	$d < 0.1mm$	$C_D = \frac{24}{R_e}$	$v_s = \frac{(G-1)\gamma_w d^2}{18\mu}$
$0.5 < R_e < 10^4$	$0.1 < d < 1mm$	$C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34 \approx \frac{18.5}{Re^{0.6}}$	$v_s = \left[\frac{g(G-1)d^{1.6}}{13.88 \nu^{0.6}} \right]^{0.714}$
$10^3 - 10^4 < R_e$	$d > 1mm$	$C_D = 0.4$	$v_s = 1.8\sqrt{gd(G-1)}$

- ◆ **Stoke's Law** ($d < 0.1mm$)

$$v_s = \frac{(G-1)\gamma_w d^2}{18\mu}$$

- For temperature $T^\circ C$

$$v_s (mm/s) = 418(G-1)d_{mm}^2 \left(\frac{3T+70}{100} \right)$$

- **DESIGN Elements**

Detention period	It is theoretical time taken by a particle of water to pass between entry and exit of a settling tank. The value of detention period depends upon the type of suspended impurities in water, and may vary from 4 to 8 hours in plain sedimentation tanks. $t_d = \frac{V}{Q}$
Flowing through period	It is average time required for a batch of water to pass through the settling tank. It is always less than detention period due to short circuit effects.
Displacement efficiency	It is defined as the ratio of flowing through period to the detention period. If displacement efficiency is more, short circuiting is less. $\eta_d = \frac{t_d}{t_f}$
Overflow rate/surface loading	The quantity of water passing per hour per unit horizontal area is known as the overflow rate or surface loading. It is numerically equal to velocity of settlement. $v_s = \frac{Q}{A}$
Basin dimensions	The surface area of the basin is determined on the basis of the overflow rate or surface loading rate. $A = \frac{V}{SLR}$ The length and width ratio of rectangular tanks should be 3:1 to 5:1, the depth is kept between 2.5 to 5m.
Settling tank efficiency	Settling tank efficiency is reduced by: eddy currents (inertia), surface currents (due to winds), vertical convection currents (thermal gradient), density currents (density due to temperature). % removal of smaller particles $= \frac{v'_s}{v_s} \times 100$ $= \frac{d'^2}{d^2} \times 100 \text{ (laminar)}$ Efficiency of tank = $\frac{\% \text{ removed}}{\text{total present}} \times 100$
Vertical flow type	These are less efficient than horizontal flow types. $V = D^2(0.011D + 0.785H)$

g) Filtration

- Filtration remove flocks and smaller un-sedimented particles. It also removes dissolved organic matter, minerals and microorganisms. When water is filtered through the bed of filter media, following actions take place:
 - ◆ *Mechanical straining*: suspended particles are usually larger than pore spaces of filter media, hence they are arrested and removed, the major removal takes place only in the upper few centimeters of the filter media. These arrested particles form a mat, and further help in straining the impurities.
 - ◆ *Sedimentation*: due to removal of turbulence from water, particles settle down on the surface of sand grains.
 - ◆ *Biological action*: after initial run, upper layer of sand grains become coated with reddish brown sticky deposit of partly decomposed organic matter together with iron, manganese, Aluminium and silica. Where algae, bacteria, protozoa exist. This film is called *schmutzdecke* or dirty skin. Bacteria not only break-down organic impurities, and convert them into harmless compounds, but also destroy each other.
 - ◆ *Electrolytic action*: sand grains in filter and impurities have opposite charges, during interaction charges gets neutralized and during back washing get removed.
- Filter media
 - ◆ Sand: it is the cheapest filter medium and is widely used. Sand used for filters should be free from clay, silt, loam, suspended matter and other organic matter. It should be fairly uniform and of proper size.

Type	Slow Sand	Rapid sand
Effective size	0.2 to 0.3mm	0.45 to 0.7mm
Uniformity coefficient	3 to 5	1.3 to 1.7

- *Preparation of sand* for rapid sand filter (MAINS)
 - River sand may be too coarse or too fine or too uniform to meet the specifications in terms of effective size and uniformity coefficient.
 - The specified sizing and uniformity are obtained by size cumulative percentage curve, the grains size corresponding to percentage is calculated for too fine and too coarse sand.
 - Coarse sands are removed by sieving while the size below the minimum is removed by sand washer (it is a type of up-flow settling tank).
 - ◆ Anthracite: crushed anthracite has been successfully used as filter medium as a substitute for sand in some filters and may be used in conjunction with sand and other materials in mixed media filters. It is costlier per ton than sand but has greater volume per unit weight.
 - ◆ Garnet sand: it has high specific gravity (4.2) and is a dense material. Because of its high cost it cannot be used as a sole filter material however, it may be used as a constituent in mixed media filter.
- **Slow sand filter**
 - ◆ They are so called because the rate of filtration through them may be only twentieth or less, of rate of filtration through rapid gravity filters. Because of low filtration rates, slow sand filters require **large areas of land and are costly to install**. They are also expensive to operate due to laborious method of bed cleaning by surface scrapping.
 - ◆ In *slow sand filter*, filtering action mostly takes place at or near the surface of the sand. At the surface a layer (**schmutzdecke**) rapidly builds up due to biological metabolism of organic impurities into harmless compounds. This layer further helps in absorbing and straining out the impurities.
 - ◆ They do not utilize coagulation to prepare water for filtration and only pretreatment used is plain sedimentation. Due to this, the SSF are not suitable for dealing with waters containing any appreciable quantity of suspended matter.

- ◆ The normal rate of flow in slow sand filters may be between 100 to 200 liters per hour per m² of filter area. They are highly effective in removal of bacterial load from water. They are expected to remove 98 to 99% of bacteria in water, under normal conditions. For achieving even higher efficiency, they can be operated at even slower rate or with some preliminary treatment and chlorine.
- ◆ The **SSF do not materially reduce the true colour of water**. It is also not effective in removing colloidal turbidity over 50 ppm, and high concentration of manganese in solution.
- ◆ But is effective in removing algae and musty or earthy odour and taste. The filters water contains less nutrients and has reduced possibility of after growth of low organisms in the distribution system.

Design considerations	Number of filters
Gravel layer is provided only to support the sand layer.	$Area (m^2) = \text{no of filters}$
Depth of tank 2.5 to 3.5 m.	$< 20 = 2(1 + 1)$
Plan area required is 100 to 2000 m ²	$20 - 240 = 3(2 + 1)$
Depth of sand is 90 to 110 cm and depth of water over it is approximately the same	$250 - 649 = 4(3 + 1)$
	$650 - 1200 = 5(4 + 1)$
	$1201 \text{ onwards} = 6(5 + 1)$

- **Rapid sand filter**
 - ◆ Gravity flow:
 - The enclosure tank is usually smaller in size and is therefore placed under a roof. The depth may vary between 2.5 to 3.5m.
 - Sands due to increased effective size and decreases uniformity coefficient, the void space is increased, resulting in increased filtration rate. The filter sand media is supported on base material consisting of graded gravel layers.
 - Under-drainage system serves two purposes. (i) it collects filtered water (ii) it provides uniform distribution of backwash water without disturbing the gravel bed.
 - As water is filtered, impurities are arrested by filter media, due to which loss of head goes on increasing. A stage comes when the frictional resistance exceeds the static head above the sand bed. At this, lower portion of the media and under drainage are under *partial vacuum or negative head*. Water is then sucked through the filter media rather than being filtered through it. Due to formation of negative head, dissolved gases and air are released filling the pores of the filter. The filter then becomes **air bound**, head losses rise sharply, and filter output capacity drops rapidly.
 - Permissible head loss may be 2.5 to 3.5 m and permissible *negative head* may be 0.8 to 1.2 m. a filter run is terminated when these limits are reached and the filter is then back washed. Under normal conditions, the frequency of filter wash may be between 2 and 4 days.
- Operational troubles
 - ◆ **Air binding**: air bubbles occupy the void spaces and reduce filtration rate. It is caused by
 - Negative head
 - Increase of temperature of water as it passes through filter media, resulting in reduction in capacity to retain gases.
 - Release of oxygen by algae.
 - ◆ **Mudball formation**: mud from atmosphere get deposited on sand surface, due to in-adequate washing mud sink down into sand bed. This mud stick to sand grains and other arrested impurities forming mudballs. Which interferes with upward movement of backwash causing turbulence and removal of sand particles. Once started they keep on increasing in number, to avoid it surface washing, racking and washing with caustic soda is adopted. Sometimes use of deflocculating agent (sodium salt) during backwashing helps.

- ♦ *Cracking of filter*: the compression and shrinkage of soft, gelatinous coating on sand grains tend to form cracks in the filter. The effect of such cracks is to permit the dirty matter to penetrate into the filter media, sometimes up to gravel layer reducing the efficiency of filter.
- Pressurized flow: flow of water is under pressure, used for clarifying softened water at industrial plants and in treating swimming pool water.
- DESIGN steps

Operational troubles & methods to overcome

- Incrustation of sand – washing with sodium hydroxide or bleaching powder
- Air binding – increasing in depth of water
- Mud ball formation – compressed air scouring, backwashing, manual surface raking
- Slime growth – through backwashing with salt solution and soaking the filter in it.

Filter design

Find daily maximum demand = $1.8 \times ADD$

Total daily demand = Daily maximum \times Population

Increasing value for Back washing $Q = \text{Total daily demand} \times (1 + \% \text{increase})$

Adjusting for wash time $Q' = \frac{24}{24 - \text{back wash time}} \times Q$

$$\text{Total Area} = \frac{Q'}{\text{filter rate}}$$

Number of filters $n = 1.22\sqrt{Q(MLD)}$ operational + 1 standby

Assuming L: B = 1.5:1 find dimension of filter

Manifold laterals underdrainage design

Total area of perforation

$$A_{Tp} = 0.2\% \times \text{filter area}$$

Total area of laterals $A_{TL} = 2 \times A_{Tp}$

Total area of manifold $A_m = 2 \times A_{TL}$

Diameter of manifold $\phi_m = \sqrt{\frac{4}{\pi} A_m}$

Assuming spacing between laterals 15 to 30 cm,

Find number of laterals $n = 2 \left(\frac{\text{length of filter}}{\text{spacing}} + 1 \right)$

Find total number of perforations $n_p = \frac{A_{Tp}}{\frac{\pi}{4} \phi_p^2}$, take diameter 13mm

Number of perforations in each lateral $x = \frac{n}{n_p}$

Diameter of lateral is twice the area of perforation in each lateral $\phi_L = \sqrt{2x} \phi_p$

Check

$\frac{\text{length of each lateral}}{\text{diameter of lateral}} \geq 60$

Assuming water rise (15-90 cm/min) find $Q_{wash} = A \times \text{rise}$

Maximum permissible velocity in manifold $v = \frac{Q_{wash}}{A_m} < 1.8 \text{ to } 2.4 \text{ m/sec}$

Backwash expanded bed

The rate of washing is 15 to 90 cm/min, normally it is taken as 45 cm rise/min

To hydraulically expand a bed, the head-loss required to expand the sand bed

$$H_l = D(1 - n)(G - 1)$$

Head-loss through the expanded bed is same as in case of unexpanded bed

$$H'_l = D'(1 - n')(G - 1)$$

$$D(1 - n) = D'(1 - n')$$

Porosity of expanded bed is a function of backwash velocity v_B and settling velocity v_s

$$n' = \left(\frac{v_b}{v_s} \right)^{0.22}$$

$$v_b = \frac{Q_b}{\text{surface area}}$$

- Comparison between slow and rapid sand filters

	Slow sand filter	Rapid sand filter
Rate of filtration	100 to 200 l/hr/m ²	3000 to 6000 l/hr/m ²
Loss of head	15 cm initial to 100 cm final	30 cm initial to 3 m final
Coagulation	Not required	Essential
Filter media of sand	Effective size 0.2 to 0.35 mm $C_u = 2$ to 3 Depth = 105 cm	Effective size 0.35 to 0.6 mm $C_u = 1.2$ to 1.7 Depth = 105 cm
Underdrainage	Split tiles laterals discharging into tile or concrete main drain or perforated pipe laterals	Perforated laterals with mains or wheeler system.
Method of cleaning	Scrapping of top layer to 15 mm to 25 mm	Agitation and back washing with or without compressed air.
Period of cleaning	1 to 2 months	2 to 3 days
Penetration of suspended matter	Superficial	Deep
Efficiency	Very efficient in the removal of bacteria but less efficient in the removal of colour and turbidity	Less efficient in the removal of bacteria, more efficient in the removal of colour and turbidity
Economy	High initial cost	Cheap and economical
Flexibility	Not flexible in meeting variation in demand	Quite flexible for reasonable fluctuations in demand
Skilled supervision	Not essential	Essential

h) Softening

- Lime soda process:
 - ◆ Lime helps in removing the entire carbonate hardness (Carbonate hardness of Ca as well as Mg), and it reacts with non-carbonate hardness of Mg to convert the same into non-carbonate hardness of Ca. The non-carbonate hardness is finally removed by soda. Lime also helps in removing free dissolved carbon dioxide, if and when it exists.
 - ◆ Precipitate of calcium carbonate is formed at $\text{pH} > 9 - 9.5$, precipitate $\text{Mg}(\text{OH})_2$ is formed at $\text{pH} > 11$, if pH is not in above mentioned range, it is first increased before addition of lime and soda.
 - ◆ Complete removal of hardness by chemical precipitation cannot be achieved under normal treatment as up to 40mg/l of CaCO_3 and up to 10mg/l of $\text{Mg}(\text{OH})_2$ is formed very slowly and remains in soften water which if allowed to enter into distribution system would lead to incrustation in pipes hence; **re-carbonation** is done in the end to re-dissolve precipitates.
 - ◆ The amount of soda and lime required can be computed using:
 - Lime $\text{CaO} = 40 + 16 = 56$
 - Slaked lime $\text{Ca}(\text{OH})_2 = 40 + 16 \times 2 + 2 = 74$
 - Soda Ash $\text{Na}_2\text{CO}_3 = 2 \times 23 + 12 + 16 \times 3 = 106$

Type of Hardness	Chemical Required	Molecular weight	Lime	Soda
CaCO_3 alkalinity	Lime	$40 + 12 + 16 \times 3 = 100$	$= x \frac{56}{100}$	
$\text{Ca}(\text{HCO}_3)_2$	Lime	$40 + 16 \times 6 + 12 \times 2 + 2 = 162$	$= x \frac{56}{162}$	
$\text{Mg}(\text{HCO}_3)_2$	Lime (2 units)	$24 + 16 \times 6 + 12 \times 2 + 2 = 146$	$= x \frac{56 \times 2}{146}$	
MgSO_4	Lime + Soda	$24 + 32 + 16 \times 4 = 120$	$= x \frac{56}{120}$	$= x \frac{106}{120}$

MgCl ₂	Lime + Soda	$24 + 35.5 \times 2 = 95$	$= x \frac{56}{95}$	$= x \frac{106}{95}$
CaSO ₄	Soda ash	$40 + 32 + 16 \times 4 = 136$		$= x \frac{106}{136}$
CaCl ₂	Soda ash	$40 + 35 \times 2 = 110$		$= x \frac{106}{110}$

- ◆ Large quantity of sludge is formed when this method is used, dry weight of which can be computed in **mg/l**

$$\text{Dry sludge} = (Ca_R + 0.58 Mg_R + LA)$$
 - Ca_R calcium hardness removed in mg/l expressed as CaCO₃
 - Mg_R Magnesium hardness removed in mg/l expressed as CaCO₃
 - LA lime added in mg/l expressed as CaCO₃
- ◆ Lime and soda are added with coagulant and re-carbonation is done before filtration.
- Zeolite method (cation exchange)
 - ◆ Zeolites are natural salts or clays which are, hydrated silicate of aluminum and sodium. They can also be manufactured synthetically and are called **Resins**.
 - ◆ Water when passed, exchange its univalent Sodium with multivalent cation causing hardness and get itself converted to exhausted zeolite, which is further regenerated by passing 5-10% of brine solution.
 - ◆ This process gives zero hardness water and does not leads to formation of sludge while removing hardness.
 - ◆ This process becomes **costly if Fe and Mn are present** as regeneration of Fe/Mn does not take place.
- Demineralization
 - ◆ Demineralization is the process of removing mineral salts from Water by using the ion exchange process. Demineralised Water is completely free of dissolved minerals. Treatment is done in two stages.
 - ◆ In 1st stage water is passed through cation exchange resins but induces acidity, which is removed by passing acidic water through anion exchange resins in next stage.
 - ◆ Exhausted cation exchange resins is regenerated by passing acidic solution and exhausted anion exchange resins is regenerated by passing alkaline solution of soda ash through it.
 - ◆ Major application: Boilers feed Water, Textiles, Pharmaceuticals, Chemicals, Breweries, battery, fertilizers.

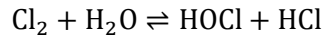
i) Disinfection

- It may be defined as the process of destruction of harmful micro-organism from water. **Sterilization** is process of removal of all types of micro-organism from water.
- Minor methods of treatment
 - ◆ Treatment with ozone:
 - ozone when added to water dissociates into molecular oxygen and nascent oxygen, which is a powerful oxidizing agent, removes both organic matter and micro-organisms from water, by destroying cell walls. Ozone doesn't remain in distribution system and hence does not safe-guard water future re-contamination. It removes taste colour and odour also and gives a pleasant taste to water. It is less efficient than chlorine in killing bacteria. Its normal dose varies between 2-3 ppm.
 - ◆ Treatment with potassium permanganate:
 - This is a common method of treatment in **rural areas** where water supplies are from wells, which contain lesser number of bacteria. Besides killing bacteria, it also helps in oxidizing organic matter.
 - KMnO₄ is mixed with water in a bucket and added to well. Pink colour forms because of this, if pink colour disappears organic matter is present, and **further addition of KMnO₄ is done till pink colour stands**. The well is not used for 48 hours.

- The normal dose of this disinfectant varies from 1 to 2mg/l with contact period of 4 to 6 hrs.
- It removes 100% bacteria causing cholera, it is also effective in removal of taste and odour and inorganic impurities.

- **Chlorination**

- ◆ The precise action by which chlorine kills bacteria in water is not known. A commonly accepted theory is *Enzymatic Hypothesis*. According to this, chlorine compounds formed when chlorine is added to water, interfere with certain enzymes in the bacterial cells which are vital for the support of life.
- ◆ When chlorine is dissolved in water, it reacts to form hypochlorous and hydrochloric acids.



- ◆ The hypochlorous acid, HOCl, ionizes into H⁺ ions and hypochlorite OCl⁻ ions. This reaction is reversible and depends upon the pH of water. Above 10 only OCl⁻ will exist, and at pH 5 to 7 HOCl will exist.
- ◆ Chlorine existing in water as *hypochlorous acid, hypochlorite ions and molecular chlorine* is defined as **free available chlorine**. HOCl is about 80 times as effective as hypochlorite ion, that's why pH of water to be treated should be maintained at less than 7 to prevent great ionization of HOCl.
- ◆ **Chlorine demand**: chlorine and chlorine compounds, by virtue of their oxidizing power, first reacts with organic as well as inorganic impurities present in water. The amount of chlorine consumed in the oxidation of these impurities, before any disinfection is achieved, is known as *chlorine demand*. Chlorine demand is, therefore, the difference between the amount of chlorine added to water and the quantity of free available chlorine remaining at the end of a specified contact period.
 - **Demand = dosage – residual**
- ◆ Generally, most waters are satisfactorily disinfected if the free available residual chlorine is about 0.2 mg/l at the end of 10 minutes contact period.

- **Chloramines**

- ◆ If ammonia is present in water, chlorine react to form chloramines, which are less effective, but are stable and remain in water for greater duration and safeguards it against future recontamination.
- ◆ They are weaker as compared to free chlorine but do not cause bad taste when left as residue, particularly those due to phenol.
- ◆ NH₃ is added to water just before chlorine is applied. Following reactions take place:

$\text{NH}_3 + \text{HOCl} \rightarrow \text{H}_2\text{O} + \text{NH}_2\text{Cl}$	Mono chloramine	pH > 7.5
$\text{NH}_2\text{Cl} + \text{HOCl} \rightarrow \text{H}_2\text{O} + \text{NHCl}_2$	Di chloramine	5 < pH < 6.5
$\text{NHCl}_2 + \text{HOCl} \rightarrow \text{H}_2\text{O} + \text{NCl}_3$	Tri chloramine	pH < 4.4
- ◆ The combined chlorine with ammonia in the form of chloramines is called the **combined chlorine**, and is much less effective in causing disinfection compared to the free chlorine, being about 25 times less effective.

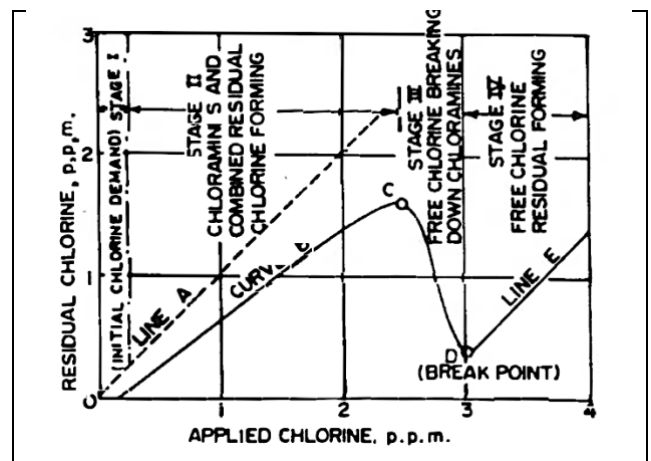
- **Forms of chlorination**: depending upon the stage at which chlorine is applied to water

Plain chlorination	This term is used to indicate that only the chlorine treatment and no other treatment has been given to the raw water. It removes bacteria, organic matter and color. It is used for relatively clear water with turbidity less than 20 to 30ppm.
Pre-chlorination	<ul style="list-style-type: none"> ➤ It is application of chlorine to water before its treatment specially before filtration or sedimentation. ➤ This helps in reducing the amount of coagulant required because of oxidation of organic matter. It reduces bacterial load on filters, helps in maintaining longer filter runs, also controls algae and planktons in basins and filters.

	➤ It prevents putrefaction of sludge in settling basins and eliminates tastes and odour.
Post-chlorination	It is application of chlorine to water after treatment. This is standard form of chlorination in which chlorine is added to water as it leaves the rapid filters and before it enters the distribution system
Double chlorination	Pre-chlorination and Post chlorination are combinedly done. This is done specially when raw water is highly contaminated and contains large amounts of bacterial life and other organic matter is present.
Super chlorination	When excess chlorine is added in water during epidemic such that it gives a residual of 1-2mg/l beyond break point. It is followed by a contact period of 30 to 60 minutes, after that the residual chlorine is discharged by means of dechlorinating agents.
Dechlorination	➤ It is the process of removing excess chlorine from water before distribution to consumers to avoid chlorine taste. ➤ It is achieved either by aeration or by use of chemicals such as Sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$), sodium metabisulphate ($\text{Na}_2\text{S}_2\text{O}_5$), sodium sulphite (Na_2SO_3), sodium bi sulphite (NaHSO_3), activated carbon, potassium permanganate, sulphur dioxide.

- **Break point chlorination:**

- ◆ When chlorine is added to pure water, which has no chlorine demand, a curve at 45° is obtained between residual chlorine and applied chlorine. (straight line)
- ◆ **Stage I:** chlorine first reacts with inorganic impurities such as Fe^{2+} , S^{2-} , Mn^{2+} , NO_2^- that converts chlorine into chloride, which has no residual oxidizing power.
- ◆ **Stage II:** Excess chlorine after this point is consumed by ammonia to form chloramines. These combined chlorines gradually increase with the addition of chlorine. However, some chlorine is consumed for killing bacteria and thus the amount of residual chlorine shall be slightly less than that added ($< 45^\circ$). A point is reached where the amount of combined residual chlorine is maximum, and bad smell start coming out.
- ◆ **Stage III:** Further increase in applied chlorine results in decrease in the residual chlorine, indicating the **beginning of oxidation of organic matter**. During this action, the free chlorine breaks down chloramines changing them to nitrogen compounds while the chlorine residual actually drops. A point is reached where bad smell and taste suddenly disappear and oxidation of organic matter is complete.
- ◆ **Stage IV:** Further addition of applied chlorine results in increase in the residual chlorine at 45°.
 - The **break point** in the chlorination of water may be defined as the point on applied-residual chlorine curve at which all, or nearly all, the residual chlorine is free chlorine.



- Tests for determining chlorine residuals

- ◆ The amount of residual chlorine left in the chlorinated water after the required contact period can be experimentally determined by:
- ◆ **Orthotolidine test:** (colour matching) The breakpoint stage is determined by this laboratory test. It is represented by instantaneous **yellow colour**.

- The orthotolidine test will normally give the total residual chlorine present in water. However, it may be adjusted so as to give separately the quantities of free as well as combined chlorine.
- The orthotolidine test, however, is not a fool-proof, because the impurities such as **iron, manganese, nitrite** are likely to cause **false yellow color** thereby indicating increases chlorine residue. For such water orthotolidene arsenite test is performed.
- ◆ **Starch iodide test:** it is used if nitrite, manganic compounds are present, it gives more precise results than orthotolidene test. (titration)
 - Starch iodide test is **laborious and costly** and hence generally not used for testing public supplies
- ◆ **Chlorotex test:** it is a very simple test and uses BDH Chlorotex reagent. (colour matching)
- ◆ **DPD test:** this test is widely used in modern days, uses colour matching, red colour.
- Factors affecting disinfection with chlorine
 - ◆ Turbidity ↑ efficiency ↓
 - ◆ Metallic compounds such as iron and manganese utilize amount of chlorine to convert to higher stages of oxidation.
 - ◆ Ammonia form combined available chlorine which is not so effective as free chlorine.
 - ◆ pH ↑ efficiency ↓
 - ◆ temperature: reduction in temperature of water results in substantial decrease in killing power.
 - ◆ Time of contact ↑ efficiency ↑
- j) Minor methods of treatment
 - Activated carbon, due to its adsorption property it removes taste, odour, phenol, excess chlorine, iron, manganese from water.
 - Copper Sulphate is used to serve two purpose
 - ◆ Removal of colour, odour and taste from water.
 - ◆ Control of growth of algae, bacteria and aquatic weeds in water reservoirs.
 - Removal of iron and manganese
 - ◆
 - Fluoridation is the process of raising the fluoride content of water. The fluoride compounds that are adopted for fluoridation are: sodium fluoride (NaF), sodium silico fluoride (Na₂SiF₆), hydrofluosilicic acid (H₂SiF₆)
 - **De-fluoridation** is the process of reducing the fluoride concentration of water. It can be achieved by using (i) calcium phosphates, bone (ii) Bone charcoal (iii) synthetic tri-calcium phosphate Ca₃(PO₄)₂ (iv) activated carbon (v) lime + Alum (*Nalagonda technique*)
 - De-salination: it is the process of removal of salts from water, it can be achieved by
 - ◆ Reverse osmosis
 - ◆ Evaporation and distillation
 - ◆ Freezing
 - ◆ Electrodialysis

5. Conveyance of water

a) Pipes

Cast iron pipes	<p>They are used in great majority of water distribution mains because of centuries of satisfactory experience with it.</p> <p>Advantages</p> <ul style="list-style-type: none"> ➤ They are of moderate cost ➤ Their jointing is easier ➤ They are resistant to corrosion ➤ They have long life ➤ Service connection can be easily made in them
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	<p>Disadvantages</p> <ul style="list-style-type: none"> ➤ They are subjected to tuberculation in certain waters, due to which their carrying capacity is reduced. ➤ They are heavier and hence uneconomical when their diameter is more than 120cm ➤ They cannot be used for pressure greater than 7kg/cm² ➤ They are fragile
Wrought iron	Wrought iron pipes are manufactured by rolling flat plates of wrought iron to proper diameter and welding the edges. Such pipes are much lighter than CI pipes and can be more easily cut, threaded and worked. They look much neater and are costlier, <u>they corrode</u> quickly and hence are used principally for installation within buildings.
Galvanized iron pipe	GI pipes are coated with thin film of molten zinc, they can be joined by screwed and socketed joints.
Steel pipe	<p>These pipes of small diameter can be made directly but larger sizes are made by riveting or welding together suitably curved plates.</p> <ul style="list-style-type: none"> ➤ These pipes cannot be easily made to resist high external pressures; hence they should be placed under favorable condition in which high external pressure are not expected to fall on the pipes. ➤ They are particularly suitable on bridges or under similar conditions where strength and low weight are desired. ➤ Difficult to make joints.
Cement pipe	<p>Reinforced concrete pipes are used for large water supply lines, but they are not suitable for distribution systems.</p> <p>Advantages</p> <ul style="list-style-type: none"> ➤ They are more suitable to resist external loads and loads due to backfilling. ➤ Maintenance cost is low, inside surface can be made smooth to reduce frictional losses. ➤ No corrosion is there, pipes can be cast at site hence reducing transportation problem. ➤ Due to heavy weight, problem of floatation is not there when they are empty. ➤ Expansion joints are not normally required. <p>Disadvantages</p> <ul style="list-style-type: none"> ➤ Tendency of leakage can be due to porosity and shrinkage cracks. ➤ Very difficult to repair them ➤ Precast pipes are heavy and difficult to transport
Asbestos pipe	<p>These are manufactured from asbestos fiber and Portland cement combined under pressure to form a dense homogeneous structure having strong bond between cement and the fiber.</p> <p>Advantages</p> <ul style="list-style-type: none"> ➤ They have smooth internal surface, due to which frictional losses are reduced. ➤ They are light and can be easily transported, they can be easily cut, fitted and joined, service connections can be easily taken. ➤ They are anti corrosive; no expansion joints are required. <p>Disadvantages</p> <ul style="list-style-type: none"> ➤ They are soft brittle, very weak under impact. ➤ They are not durable, they cannot be laid in exposed places, and are costly.

b) Joints in cast iron pipe (MAINS)

- *Spigot and socket joints*: the enlarged end of the pipe is known as the socket or bell. The socket accommodates the normal or the spigot end. Hemp or sterilized yarn is used to maintain the alignment and molten lead heated to 400°C is then poured and caulked up using chisels.
- *Flanged joint*: this type of joint is used in CI pipes with flanges. The pipes are carefully aligned before bolts are inserted and flanges are pulled together. A rubber ring is inserted between the flanges.
- *Expansion joint*: this type of joint allows the pipe to expand and contract freely under the changing temperature conditions. The space between spigot and gasket is filled with an elastic gasket.

c) Pipe appurtenances

- Sluice valves or gate valve
 - ◆ These are also known as shut off valve or stop valves. These are provided to regulate flow of water through pipe by diving the mainline into several sections.
- Air valves
 - ◆ Water flowing through pipe line always contains some air, the air tries to accumulate at high points, and may interfere with flow. Air relief valves are therefore provided at summits to provide an exit for such accumulated air.
 - ◆ Air valves are also required to discharge air when a main is being filled and to admit air when it is being emptied.
- *Reflux valves*
 - ◆ Also known as *check valve* or *non-return valve* is an automatic device which allows water to flow in one direction only.
 - ◆ They are placed in water pipes which obtain water directly from the pump. When the pump is stopped, the water in the pipe line does not rush back and damage the pump.
- Scour valves
 - ◆ Also called blow off valves or washout valves are ordinary sluice valves that are located either at the dead ends or at lowest points in the mains. They are provided to blow off or remove sand and silt deposited in pipe line. They are operated manually

6. Distribution

a) Head loss

- Dancy-Weisbach formula

$$h_f = \frac{4f'Lv^2}{2gd} = \frac{fLv^2}{2gd} = \frac{fLQ^2}{12.1d^5}$$

- ◆ f - friction factor f' - friction coefficient

- Hazen Williams formula

$$v = 0.849CR^{0.63}S^{0.54}$$

- ◆ v – mean velocity of flow in pipe (m/sec)
- ◆ C – coefficient of roughness

- Manning's formula

$$v = \frac{1}{n}R^{2/3}S^{1/2}$$

b) Hardy cross method

- In a pipe network, the algebraic sum of the pressure drops around a closed loop must be zero, the flow entering a junction must be equal to the flow leaving the junction.
- The procedure suggested by Hardy and Cross requires that the flow in each pipe is assumed by the designer, in magnitude as well as direction, in such a way that the principle of continuity is satisfied at each junction.
- The correction to these assumed flows is then computed for each pipe loop in the network.

- ◆ Head loss

$$h_f = KQ^n$$

- ◆ $n = 1.85$ Hazen William formula
- ◆ $n = 2$ Darcy-Weisbach formula

- Correction in assumed flow

$$\Delta Q = - \frac{\sum h_f}{n \cdot \sum \left| \frac{h_f}{Q} \right|}$$

- Table for iteration

Pipe name	K (given)	Assumed flow Q	$h_f = KQ^n$	$\left \frac{h_f}{Q}\right $	Corrected Q after 1 st correction
		Clock wise +	+ve	+	
		Anti-clock –	-ve	+	
		
			Σh_f	$\Sigma \left \frac{h_f}{Q}\right $	

- Apply correction in each loop, pipes common to two loops will receives both corrections, iterate.

c) Power requirement

- $P = Q(h + h_f)\gamma_w$ kW
- $BHP = \frac{P}{\eta \times 0.745}$

d) Water hammer

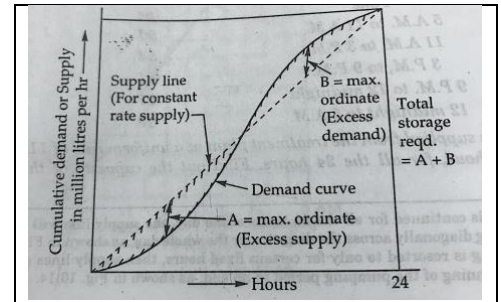
- Water hammer is produced when the velocity of water in the pipe is checked suddenly by sudden closure of a valve. When the valve is closed, there will be sudden rise in pressure due to the momentum of the moving water being destroyed. The rise in pressure in some cases may be so large that the pipe may even burst.
- Procedure
 - ◆ Find velocity of sound wave in water $c = \sqrt{\frac{K}{\rho}}$ for rigid pipe and $c = \sqrt{\frac{1}{\rho\left(\frac{1}{K} + \frac{D}{Et}\right)}}$ for elastic pipe.
 - ◆ Compute $\frac{2L}{c}$ to find whether the closure is sudden or gradual.
 - ◆ Compute pressure accordingly.

Time of closing T_c	Head developed	
Gradual case $T_c > \frac{2L}{c}$	➤ Pressure developed $p = \rho v \left(\frac{L}{T_c}\right)$	
	➤ Head developed $H = \frac{vL}{gT_c}$ v is normal velocity of water before closing.	
Sudden case $T_c \leq \frac{2L}{c}$	Rigid pipe	Elastic pipe
	➤ Pressure $p = \rho vc$ ➤ Head $H = \frac{vc}{g}$ If bulk modulus K is given $c = \sqrt{\frac{K}{\rho}}$	➤ Pressure $p = v \sqrt{\frac{\rho}{\left\{\frac{1}{K} + \frac{D}{Et}\right\}}}$ ➤ Velocity of wave $c = \sqrt{\frac{1}{\rho\left\{\frac{1}{K} + \frac{D}{Et}\right\}}}$ E – elastic modulus of pipe t – thickness of pipe

e) Service Reservoir (MAINS)

- The total storage capacity of a distribution reservoir is the summation of:
 - ◆ Balancing storage:
 - ◆ Breakdown storage: often called emergency storage is the storage preserved in order to tide over the emergencies posed by the failure of pumps, electricity or any other. 25% or 1.5 to 2 times average hourly supply.
 - ◆ Fire storage: it takes care of requirement of water for extinguishing fires. (1 to 4 liters per person per day)

- Balancing storage: the primary function of a distribution reservoir is to meet the fluctuating demand with a constant rate of supply from the treatment plant. The quantity of water required to be stored for balancing this variable demand against the constant supply is known as the balancing storage.
 - ◆ This can be worked out by utilizing the hydrographs of inflow and outflow, either by mass curve method or by using analytical tabular solution.
- Mass curve method
 - ◆ A mass curve of demand is a cumulative demand curve, obtained by continuously adding hourly demand and plotting these against time of the maximum day.
 - ◆ Line of cumulative pumping at uniform rate is plotted.
 - ◆ Draw tangents through lowest point and highest point parallel to pumping rate line.
 - ◆ The highest vertical distance between the two tangents will give the required capacity of equalizing reservoir.
 - ◆ Thus, required storage capacity is sum of morning excess and evening deficiency.
- Analytical solution
 - ◆ In this method, the cumulative hourly demand and cumulative hourly supplies are tabulated for all 24 hrs. The hourly excess of demand as well as the hourly excess of supply are then worked out.
 - ◆ The summation of maximum of excess of demand and maximum of excess of supply will give us the required storage capacity.



Time in hours of the day	Average hourly Demand	Cumulative demand	Cumulative pumping	Excess of demand	Excess of supply
1	2	3	4	$= 3 - 4$	$= 4 - 3$
				Maximum	...
				...	Maximum
			

- ◆ Total storage required = maximum excess of demand + supply

f) Layout of Distribution System

- Dead end or tree system
 - One main pipe line runs through centre and submains takeoff from this to both sides. The submains divide into several branch lines from which service connections are given.
 - Advantages
 - Design calculations are simple, pipe diameters are designed for the population likely to be served by them, so cheap and economical design.
 - Laying of pipe is simple, number of cutoff valves employed is less
 - Disadvantages
 - There is stagnation of water and accumulation of sediments due to dead ends.
 - A large number of scour valves are required, in case of repair, whole portion beyond the point need to be cutoff.
 - System is less successful in maintain satisfactory pressure in remote parts.
 - Discharge available for firefighting is limited.
- Grid iron or reticulation system
 - This system is ideal for cities laid out on rectangular plan resembling a grid-iron
 - Main supply runs through centre of rectangular area and submains takeoff from these in perpendicular directions. Branch lines interconnect all the submains.
 - Advantages
 - No stagnation problem

- Due to interconnection, water is available at each point with minimum loss of head.
- Enough water is available in streets for firefighting, since hydrant will draw water from more than one side.
- In case of repairs, only very small area is affected
- Disadvantages
 - A large number of cutoff valves are required.
 - Longer pipe length and bigger diameter pipes are required.
 - Analysis of discharge, pressure and velocities are difficult and cumbersome.
 - Cost of laying pipes is more.
- Circular or ring system
 - In this system, supply main forms a ring around the distribution area. The branches are connected cross-wise to mains and to each other. It is suitable for area having well planned streets and roads.
 - The system possesses same advantages and disadvantages as those of grid iron system. However, in case of fire, a large quantity of water is available, also the length of distribution main is much longer.
- Radial system
 - In this system the whole area is divided into a number of distribution districts. Each district has a centrally located distribution reservoir from where distribution pipes run radially towards periphery of the distribution district.
 - This system gives quick service without much loss of head. Design calculations are also simple.

II. Waste water treatment

1. Hydraulic Design of Sewers

a) Variations in flow in branch sewer (when not given)

	Maximum discharge	Minimum discharge
Daily	$= 2 \times \text{Avg. Daily discharge}$	$= \frac{2}{3} \text{Avg. Daily discharge}$
Hourly	$= 1.5 \times \text{Max Daily discharge}$	$= \frac{1}{2} \text{Min. Daily discharge}$
Hourly	$= 3 \times \text{Avg. Daily discharge}$	$= \frac{1}{3} \text{Avg. Daily discharge}$

◆ Dry weather flow = ADD

◆ Fluctuations in lateral sewers are observed to be maximum and is tapers off to main sewer.

b) Quantity of discharge

- About 80% of supplied water can be assumed as converted to sewage.
- Sewers are never designed to run at full depth, generally, the sewer pipes of sizes less than 0.4m dia are designed as running half full at maximum discharge, and sewer pipes greater than 0.4m dia are designed as running 2/3rd or 3/4th full at maximum discharge.
- Intensity of rainfall

$$I(\text{cm/hr}) = \frac{75}{t_c + 10}$$

▪ t_c is time of concentration in *minutes*

◆ $Q_p = kIA$

▪ k- Runoff coefficient

c) Hydraulic formulas for determining flow velocities in sewers and drains

Chezy's formula	$v = C\sqrt{RS}$ $C = \frac{\left(23 + \frac{0.00155}{s}\right)^{\frac{1}{n}}}{1 + \left(23 + \frac{0.00155}{s}\right)^{\frac{n}{\sqrt{R}}}}$
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Manning's formula	$v = \frac{1}{n} R^{2/3} \sqrt{S}$
Hazen and William's formula	$v = 0.85 C_H \cdot R^{0.63} S^{0.54}$ This formula is generally used for flows under pressure from designing water supply pipes, and is seldom used for designing sewers.

d) Maximum and minimum velocities to be generated in sewers

- Scouring Velocity

- ◆ A *self-cleansing velocity* may be defined as that velocity at which the solid particles will remain in suspension, without settling at the bottom of the sewer. Also, it is that velocity at which even the scour of deposited particles of a grain size will take place. Self-cleansing velocity should be maintained at **least once in a day**.

$$v_{sc} = \sqrt{\frac{8\beta}{f} (G - 1) g d_s}$$

$$v_{sc} = \frac{1}{n} R^{1/6} \sqrt{\beta d (G - 1)}$$

- β - is a dimensionless constant, indicating characteristic of sediment. Its value usually varies from 0.04 → start of scouring of clean grit, 0.8 → for full removal of sticky grit.
- f - friction factor
- ◆ Sewers are designed to carry maximum hourly discharge and checked at minimum hourly discharge for self-cleansing velocity.
- ◆ Hence, for removing the impurities mostly present in sewage (i.e. sand up to 1mm diameter and organic particles up to 5mm dia), it is necessary that a minimum velocity of about 0.45 m/s and an average velocity of 0.9 m/sec is developed in sewers.
- Maximum velocities:
 - ◆ The smooth interior surface of a sewer pipe gets scoured due to the continuous abrasion caused by the suspended solids present in sewage. This scouring and wear and tear is much more pronounced at higher velocities. This wear and tear reduce their life span and their carrying capacities.
 - ◆ Limiting velocities for vitrified tiles and glazed bricks are highest, as they are much more resistant to wear.

e) Hydraulic characteristics of Circular Sewer

- Full flow

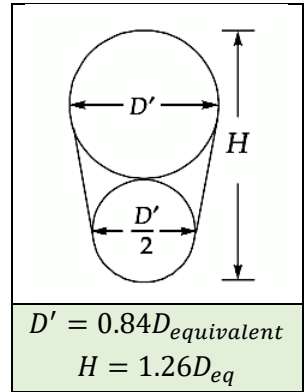
- ◆ Hydraulic radius $R = \frac{D}{4}$

- Partially full

Depth	$\frac{d}{D} = \frac{1}{2} \left(1 - \cos \frac{\alpha}{2} \right)$	Hydraulic depth	$\frac{r}{R} = 1 - \frac{360^\circ \sin \alpha}{2\pi\alpha}$
Wetted Area	$\frac{a}{A} = \left\{ \frac{\alpha}{360^\circ} - \frac{\sin \alpha}{2\pi} \right\}$	Velocity	$\frac{v}{V} = \left(\frac{r}{R} \right)^{2/3}$
Wetted Perimeter	$\frac{p}{P} = \frac{\alpha}{360^\circ}$	Discharge	$\frac{q}{Q} = \left(\frac{v}{V} \right) \left(\frac{a}{A} \right)$

- ◆ $v_{max} = 1.14 v_{avg}$ at $d = 0.81D$
- ◆ $q_{max} = 1.07 Q_{avg}$ at $d = 0.95D$
- Advantages of circular sewer:
 - ◆ They can be manufactured most easily and conveniently.
 - ◆ A circular sewer provides the maximum area for a given perimeter, and thus providing the maximum hydraulic mean depth when running full or half.
 - ◆ It utilizes the minimum quantities of materials and is therefore, the cheapest and most economical.

- ◆ A circular section, being of uniform curvature all round, offers less opportunities and for deposits.
- All these advantages of circular sections are obtained only when the sections run at least half full. When the depth goes less than half full, its merits are lost, as the velocity and discharge reduce considerably with the reduction in depth.
 - ◆ In combined sewers variations of discharge are enormous, and very low flow will be there during non-monsoon periods.
 - ◆ Hence, **egg-shaped** sewers are used for combined system
 - ◆ *Diameter of egg-shaped sewer is 0.84 times the diameter of circular sewer required and height is 1.5 times of diameter*



$$D' = 0.84D_{h\ eq}$$

$$H = 1.5D' = 1.26D_{h\ eq}$$

- f) Limitation on depth of flow due to ventilation consideration
- Because of ventilation considerations, sewers are not designed to run full even at ultimate peak flows.
 - Small sewers (< 0.4m) are generally desired to flow at 1/2 depth
 - Sewers of size between 0.4 to 0.9m are designed to flow at 2/3 depth
 - Larger sewers are designed to flow at 3/4 depth
- g) For same degree of self-cleansing
- Tractive stress will be same $\tau = \gamma R s_o$
 - ◆ $\frac{\tau_1}{\tau_2} = \frac{R_1 s_1}{R_2 s_2} = 1$
 - Substituting from Manning's equation, assuming same material and roughness
 - ◆ Ratio of velocity of same degree of cleansing will be

$$\frac{v}{V} = \left(\frac{r}{R}\right)^{1/6}$$

- h) Hydraulic equivalent section
- If two sections of different shape are hydraulically equivalent then they carry same discharge while running full at same grade and are of same material
 - For a box and circular section, relation can be established using Manning's equation
 - $D = 1.1B$
- i) Laying of sewer pipes
- All the sewer pipes are generally laid starting from their outfall ends. The advantage gained starting from tail end is the utilization of the tail length even during the initial periods of its construction.
 - The *center line* of sewer is marked by drawing an *offset line* on the ground, parallel to the centre line at a suitable fixed horizontal distance away from it.
- j) Sewer appurtenances
- Sewer appurtenances are those structures which are constructed at suitable intervals along a sewerage system, and help in its efficient operation and maintenance.

Man holes	<ul style="list-style-type: none"> ➤ These are masonry or RCC chambers, constructed at suitable intervals along the sewer lines, for providing access into them. They help in joining sewer lengths, and also helps in their inspection, cleaning and maintenance. ➤ They are provided at regular intervals in straight line, and also at points of bends, junction, change of gradient or change of sewer dia.
Drop manholes	<ul style="list-style-type: none"> ➤ When a branch sewer enters a manhole by more than 0.5m above the main sewer, the sewage is generally not allowed to fall directly into the manhole, but is brought into it through a drop pipe taken from the branch sewer to the bottom of the manhole.

	➤ The manhole in which a vertical pipe is used, is called a drop manhole, whereas, the one using an inclined pipe is called a ramp.
Lamp holes	<p>➤ These are small openings on sewers to permit the insertion of a lamp into the sewer. The lamp light is then viewed from the upstream as well as the downstream manholes. The obstructed light confirms the obstructions in the sewers.</p> <p>➤ These are especially adopted when, a bend in a sewer is necessary, construction of manhole is difficult and spacing of manholes is more than usual. They are rarely used these days and have become obsolete.</p> <p>➤ Besides its principal use as an inspection device, it can be used as a flushing device. And also, if its cover is kept perforated, it can be used for ventilation of sewers.</p>
Clean-outs	<p>It is an inclined pipe extending from the ground and connected to the underground sewer. It is used for cleaning sewer pipes. It is generally provided at the upper ends of lateral sewers in place of manholes.</p> <p>➤ The function is simple, which consists of removing the top cover, forcing water through clean-out pipe to remove obstacles in the sewer line. If obstacles are large, a flexible rod may be inserted through the clean-out pipe.</p>
Street inlets	Inlets are gullies or openings on the road surface at the lowest point for draining rain water from roads, and admitting it into the underground storm water sewers. A street inlet is a simple concrete box having gratings or openings in vertical or horizontal direction.
Catch basins	<p>Catch pits are nothing but <i>street inlets</i> provided with additional small settling basins. Grit, sand, debris etc. do settle in these basins and their entry into the sewer is thus prevented.</p> <p>A hood is also provided, which prevents the escape of foul gases, which may find its way through the sewer line.</p>

k) Ventilation of sewers

- Sewers must be properly ventilated as:
 - ◆ Decomposition and putrefaction of sewage inside the sewers may result in the production of various sewer gases, such as, carbon dioxide, carbon monoxide, methane, hydrogen sulphides, ammonia, nitrogen, etc. these gases, if not removed, may cause serious problems, and prove hazardous to the workers entering the sewers. Methane gas being highly explosive, if not removed, may even blow off the manhole covers. Ventilation also ensures a continuous flow of sewage inside the sewer.
 - ◆ Methods of ventilation
 - Use of ventilating columns: generally placed at intervals of 150 to 300m along the sewer lines.
 - Use of ventilating manhole covers
 - Proper design of sewers ensures enough ventilation as it never runs full.
 - Use of mechanical devices such as exhaust fans to expel out foul gases.
 - Unobstructed outlets
 - House vents and soil pipes

2. Waste Water Characteristics

a) Decay and decomposition of sewage

- Types of bacteria
 - ◆ **Aerobic bacteria** are those which flourish in the presence of free dissolved oxygen in wastewater, and consume organic matter for their food, and thereby oxidizing it to stable end products.

- ◆ **Anaerobic bacteria** flourish in the absence of free dissolved oxygen, since they survive by utilizing the bounded molecular oxygen in compounds like nitrates (NO_3) and sulphates (SO_4) etc, thereby reducing them to stable end products along with evolution of foul-smelling gases like H_2S , CH_4 etc.
 - ◆ **Facultative bacteria** can operate either as aerobically or anaerobically. Hence, they can survive and cause decomposition of organic matter, either in the presence or in the absence of free dissolved oxygen in wastewater.
 - Biological decomposition
 - ◆ *Aerobic decomposition*: if air or oxygen is available freely to the waste water in dissolved form, then the biodegradable organic matter will undergo aerobic decomposition, cause by aerobic bacteria as well as by facultative bacteria operating aerobically. Stable products like nitrates, carbon dioxide, sulphates are formed, along with water, heat and additional bacteria.
 - ◆ *Anaerobic decomposition*: if free dissolved oxygen is not available to the sewage, then anaerobic decomposition, called **putrefaction**, will occur. Gases like ammonia, nitrogen, hydrogen sulphides, methane, etc. are also evolved in this decomposition, producing obnoxious odour.
- b) Oxygen demand
- Chemical oxygen demand:
 - ◆ Organic matter is most often assessed in terms of oxygen required to completely oxidize the organic matter to CO_2 , H_2O and other oxidized species.
 - ◆ The oxygen required to oxidise the organic matter present in a given waste water can be theoretically computed, if the organics present in waste water are known. i.e. their chemical formula and concentrations are known, we can easily calculate the **Theoretical Oxygen Demand**.
 - ◆ But it is virtually impossible to know the details of the organic compounds present in any natural raw water or waste water. Therefore, **Chemical Oxygen Demand** is determined by performing laboratory test on given water with strong oxidant like dichromate solution. It is a measure of biodegradable as well as non-biodegradable organic matter.
 - Total organic carbon
 - ◆ Carbon is primary constituent of organic matter, and hence the chemical formula of every organic compound will reflect the extent of carbon present in that compound.
 - Bio-chemical Oxygen Demand
 - ◆ It is oxygen required for complete oxidation of biologically degradable organic matter.
 - ◆ BOD of water during 5 days at 20°C is generally taken as the standard demand and is about 68% of the total demand. A 10-day BOD is about 90% of the total.
 - ◆ It is determined in the laboratory by mixing or diluting a known volume of sample of water with a known volume of aerated pure water and then calculating DO of this diluted sample. The diluted sample is then incubated for 5 days at 20°C , after which its DO is determined.
$$\text{BOD}_5 = (\text{DO}_i - \text{DO}_f) \times \text{DF}$$
 - $\text{DF} = \frac{\text{final volume (300ml)}}{\text{Initial volume of test sample}}$ - ◆ BOD for seeded solution
 - $\text{BOD} = \text{DF} \left\{ (\text{DO}_i - \text{DO}_f) - (\text{do}_i - \text{do}_f) \times \frac{\text{seed volume}}{\text{total volume}} \right\}$
$$\text{BOD}_t = L_o [1 - e^{-kt}]$$

$$L_t = L_o [1 - 10^{-K_D t}]$$
 - ◆ L_o is called the initial oxygen demand, or Ultimate BOD. This is a fixed quantity, and does not depend upon the temperature of oxidation. The value of K_D however determines the speed of the BOD reaction

$$K_D = \frac{k}{2.3} = 0.434k$$

$$K_D T^{\circ}C = K_D 20^{\circ}(1.047)^{T-20^{\circ}}$$

- ◆ If in question it is not mentioned whether k or K_D is given, then remember that K_D value at 20°C for strong municipal sewage is of the order of 0.1 to 0.15 or slightly less.

- $ThOD \geq COD \geq BOD \geq TOC$

c) Laboratory estimation of K_D and L_0 by Thomas's graphical method

- The BOD rate constant K_D , can be computed from BOD values measured at various times. The sewage samples are tested for BOD_t values measured at various times t .
- A graph is plotted between the values of time t in days on X-axis and the values of function $\sqrt[3]{\frac{t \text{ (days)}}{Y_t \text{ BOD (mg/l)}}}$ on Y-axis. The best fit line drawn through these points is used to calculate the K_D

$$K_D = 2.62 \frac{m}{C}$$

$$L = Y_u = \frac{1}{2.3 K_D C^3}$$

- ◆ Where, m = slope of the line, C = intercept of the line on Y-axis.

d) $\frac{BOD}{COD}$ Ratio

- The value of this ratio, indicates the quality of waste water w.r.t. the type of OM i.e. Biodegradable, Non-biodegradable.
- $\frac{BOD_u}{COD}$ is always less than 1; but this value shall approach towards 1 with decreasing NBO's. This ratio is found to be between 0.92 to 1.0, for virtually fully biodegradable waste water. So $0.63 < \frac{BOD_5}{COD} < 0.68$
- If the value of this ratio is more than 0.8 then waste water is considered to be treated biologically.
- If value is less than 0.5, then waste water, it cannot be treated biologically.
- COD to TOC ratio indicates complexity of OM present. It is zero for complex OM which cannot be oxidized by potassium per magnet and 5.33 for methane.

e) Population Equivalent (PE)

- Industrial waste waters are generally compared with per capita normal domestic wastewaters, so as to rationally charge the industries for the pollution caused by them.

$$BOD_{\text{industry}} = BOD_{\text{domestic}} \times PE$$

f) Relative Stability

- The term Relative stability of a treated sewage effluent may be defined as the **ratio of available oxygen in the effluent to the total oxygen required** to satisfying its first stage BOD. It is expressed as percentage of total oxygen required and can be expressed by:

$$S_R = 100(1 - 0.630^{t_{37}})$$

$$S_R = 100(1 - 0.794^{t_{20}})$$

- ◆ t_{37}, t_{20} represents time in days for a sewer sample to decolorize a standard volume of methylene blue solution when incubated at 37°C and 20°C
- ◆ The sooner the discoloration takes place, the earlier the anaerobic condition develops, which means lesser availability of oxygen. Hence, if decolorization takes place in less than 4 days sample is considered **Unstable**.

g) Collection of sewage samples for testing

- The physical and chemical characteristics of sewage vary from top to bottom of sewage depth, as well as with time. Therefore, samples are taken at a point beneath the surface where turbulence is thoroughly mixing up sewage particles. This is called **Grab sample**. Such grab samples are collected at regular intervals during a day.

3. Disposal of Sewage

a) Standards for dilution

Dilution Factor	Degree of treatment required
Above 500	No treatment is required. Raw sewage can be directly discharged into volume of dilution water.
300-500	Primary treatment such as plain sedimentation should be given to sewage, and the effluent should not contain suspended solid more than 150 ppm
150-300	Treatment such as sedimentation, screening, and chemical precipitation are required. The sewage effluent should not contain suspended solids more than 60ppm.
Less than 150	Complete through treatment should be given to sewage. The sewage effluent should not contain suspended solids more than 30ppm. BOD ₅ should not exceed 20ppm.

b) Self-Purification of Natural stream

- When sewage is discharged into a natural body of water, the receiving water gets polluted due to waste products. But the conditions do not remain so for ever, because the natural forces of purification, such as **dilution, sedimentation, oxidation-reduction in sunlight** etc., go on acting upon the pollution elements, and bring back the water, into its original condition. This automatic purification of polluted water, in due course, is called *self-purification phenomenon*.
- The various factors on which these natural forces of purification depend are: temperature, turbulence, hydrography (velocity and surface extent), available dissolved oxygen and the amount and types of organic matter present, rate of reaeration.
- Zone of pollution in a river stream: a polluted stream undergoing self-purification can be divided into four zones:
 - ♦ **Zone of degradation:** This zone is found at certain distance downstream of point of application of effluent in river. Water in this zone is dark and turbid in comparison to water prior to it. Due to decomposition of organic matter taking place, dissolved oxygen level depletes in the river stream. Algae 🚫🌿 is not found in this zone but 🐟🐠 fishes may survive. End of this zone is characterized by depletion of DO to 40% of saturation value.
 - ♦ **Zone of active decomposition:** This is a zone of heavy pollution; hence water is darker and turbid than previous zone. Anaerobic microorganisms replace aerobic microorganisms, which produce acid, alcohols and gases, that rises to the surface and form scum layer. Both algae and fishes 🚫🌿🐟🐠 are not found in this zone. Dissolved oxygen level decreases up to its minimum value. End of this zone is characterized by increases of oxygen level back to 40% of its saturation value.
 - ♦ **Zone of recovery:** Due to almost complete decomposition of organic matter taking place, oxygen level increases and try to match its saturation value. Both 🌿🐟🐠 algae and fishes reappear, nitrate level increases and BOD level decreases in river water.
 - ♦ **Zone of cleaner water:** River attains its original condition with DO rising up to saturation level. Water becomes attractive in appearance, and game fish and usual aquatic life prevails. Some pathogenic organisms may still however survive and remain present.

• **Streeter Phelps equation**

- ♦ Oxygen deficit: it is the difference between the actual DO content of water and saturation DO content.

$$\text{Oxygen deficit (D)} = \text{Saturation DO} - \text{actual DO}$$

- ♦ Reoxygenation temperature dependence

$$K_R T^\circ = K_R 20^\circ (1.016)^{T-20}$$

- ♦ Deficit at any time D_t

- After super-imposing the rates of de-oxygenation and re-oxygenation mathematically, the obtained results expressed in the form of famous Streeter-Phelps equation.

- D_t = it is dissolved oxygen deficit in mg/l after t days.

$$D_t = \frac{K_D L_o}{K_R - K_D} [10^{-K_D t} - 10^{-K_R t}] + D_o 10^{-K_R t}$$

- D_o is initial Oxygen deficit of the mix at the mixing point.
- L_o is ultimate first stage **BOD of mixture** of waste water and stream

- ◆ Critical time (t_c) after which the minimum DO can be found by differentiating above equation and equating it to zero. $t_c =$

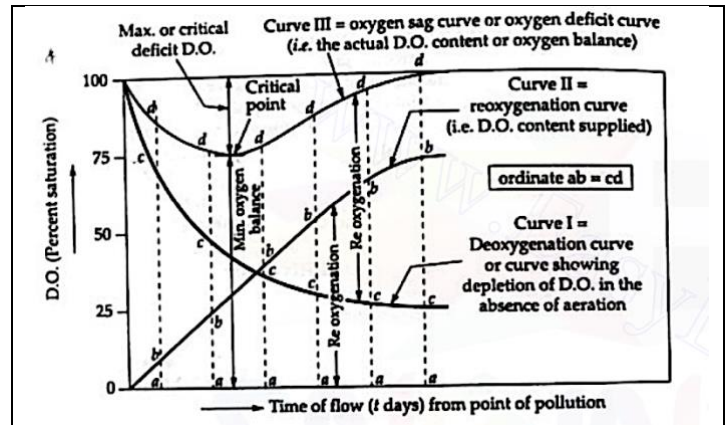
$$\frac{1}{K_R - K_D} \log \frac{K_R}{K_D} \left[1 - \frac{D_o(K_R - K_D)}{K_D L_o} \right]$$

- ◆ Critical oxygen deficit or maximum oxygen deficit

$$D_c = \frac{K_D}{K_R} L_o 10^{-K_D t_c}$$

- ◆ Self-purification constant $f = \frac{K_R}{K_D}$

- ◆ Using self-purification constant modified equations are



$$t_c = \frac{1}{K_D(f-1)} \log \left[f \left(1 - (f-1) \frac{D_o}{L_o} \right) \right]$$

$$D_c = \frac{L_o}{f} 10^{-K_D t_c}$$

$$\left(\frac{L_o}{f D_c} \right)^{f-1} = f \left\{ 1 - (f-1) \frac{D_o}{L_o} \right\}$$

- $D_o = D_{sat} - \frac{DO \times Q_w + DO \times Q_r}{Q_r + Q_w}$
- $BOD_{mix} = \frac{BOD_w \times Q_w + BOD_r \times Q_r}{Q_w + Q_r}$
- $L_o = \frac{BOD_{mix}}{1 - 10^{-K_D \cdot 5}}$
- If expansion factor is given then $Q'_w = Q_w \times 1.1$

- ◆ Use 3rd equation when, we are required to find L_o from D_c , where questions ask for degree of treatment required for given minimum DO value.

c) Disposal of waste water in lakes

• Stratification in lakes

- ◆ Water in lakes in temperate regions in summers, divide itself into upper layer of warm circulating water referred as **Epilimnion**. And lower cooler layer having deficiency of oxygen as **Hypolimnion**. Both these layers are separated by narrow layer of steep temperature gradient called **Metolimnion** or **Thermocline**. This stratification is interrupted twice in a year, once during spring and once during extreme winters.

• Biological zones in lakes

- ◆ Lakes have been found to exhibit distinct zones of biological activity, largely determined by the availability of light and oxygen. The most important biological zones are:
 - Euphotic zone: it is upper layer of lake water through which sunlight can penetrate. All the plant growth occurs in this zone. Its depth gets reduced by turbidity.
 - Littoral zone: The shallow water near the shore, in which rooted plant grow, is called the littoral zone.
 - Benthic zone: The bottom sediments in a lake comprises this zone. As the aquatic life dies, they settle down to the bottom, where they are decomposed by the organisms living in the benthic zone.

- Productivity of a lake: the productivity of a lake is defined as a measure of its ability to support a food chain. Since algae forms the base of this food chain, its presence measures the lake productivity. Depending upon increasing level of productivity, lakes may be classified as:

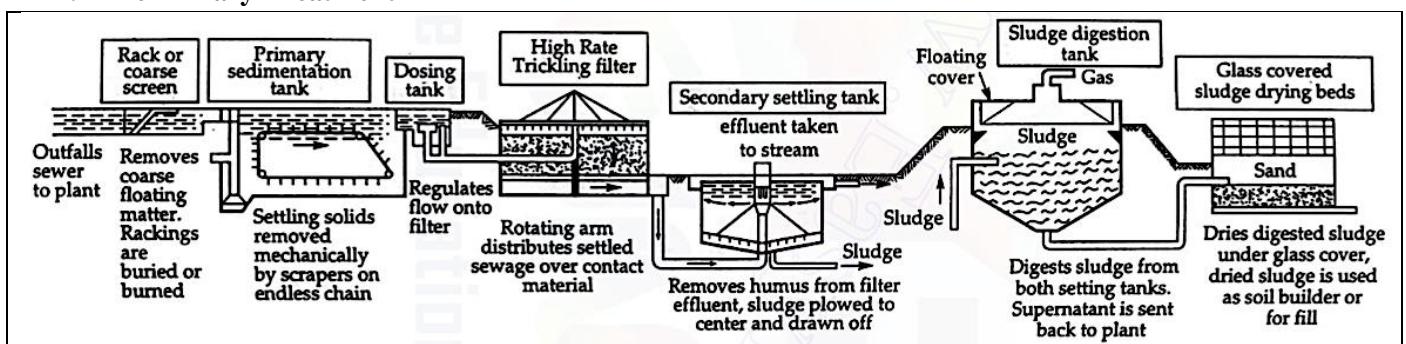
- ◆ **Oligotrophic** lakes: these are the lakes of least productivity levels hence supports, no or negligible growth of algae. These are fresh water lakes, which are generally found in Antarctica. Sunlight is able to penetrate up to hypolimnion layer. Due to sufficient availability of oxygen in these lakes, these are classified as Aerobic lakes.
- ◆ **Mesotrophic** lakes: these are lakes of intermediate productivity level, hence supports intermediate growth of algae. Although substantial depletion of oxygen may occur in the hypolimnion, yet it remains aerobic.

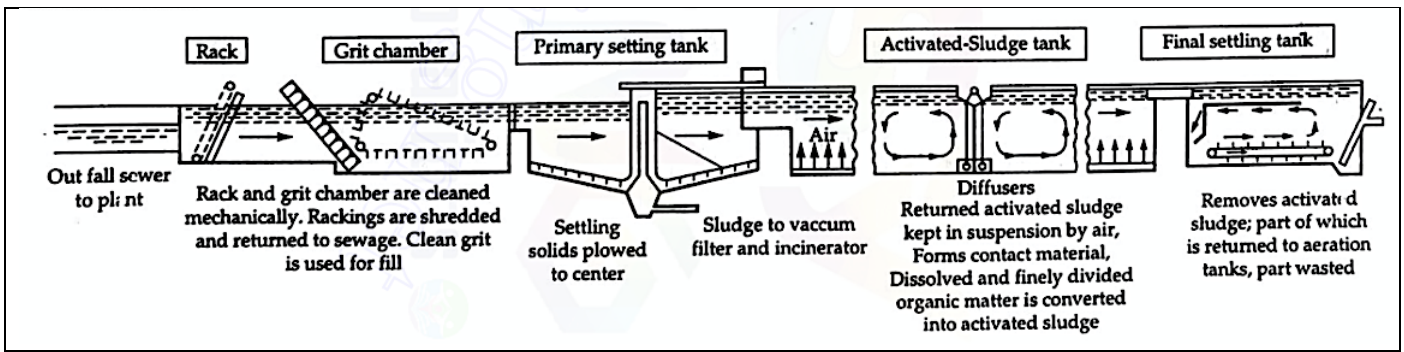
- ◆ **Eutrophic** lakes: these are lakes of high productivity levels and support high growth of algae. Penetration of sunlight in these are limited to epilimnion layer. They are anaerobic.
- ◆ **Senescent** lakes: these are very old shallow lakes, having thick organic sediment deposits at their bottom. Rooted water plants abundantly grow in such ponds, which ultimately becomes marshes.
- Eutrophication of lakes:
 - ◆ Eutrophication is a natural process under which lakes get infested with algae and silt up gradually to become shallower and more productive through the entry and cycling of nutrients like carbon, nitrogen and phosphorous.
 - ◆ The increased phosphorous in lake water, entering either through agricultural use of its drainage area or through entry of domestic and industrial waste water, will cause accelerated eutrophication of lakes, and is called **cultural eutrophication**.
 - ◆ Eutrophic lakes are, however, not necessarily polluted, but pollution contributes to eutrophication.
 - ◆ In order to remove algae **copper Sulphate or lime can be added**, but to avoid eutrophication entry of nutrients must be restricted.
- d) Disposal of water in sea water
 - Sea water normally contains 20% less oxygen than that contained in fresh water of a river.
 - Disposal of sewage is done far away from shores, below the water surface level and only during low tides.
- e) Disposal on land
 - Disposal of sewage effluent on land for irrigation
 - ◆ If the soil to be irrigated is sand and porous, the sewage effluent may contain more solids and other wastes, and thus requiring less treatment as compared to case where soil is less porous and sticky.
 - ◆ Difference between Effluent irrigation and sewage farming is that in **effluent irrigation** the chief consideration is *the successful disposal of sewage* while in **sewage farming** chief consideration is the *successful growing of crops*.
 - Sewage sickness
 - ◆ When sewage is applied continuously on a piece of land, the soil pores or voids may get filled up and clogged with sewage solids retained on them, which prevents free circulation of air, and anaerobic conditions will develop, releasing foul gases like hydrogen sulphides, carbon dioxide and methane. This phenomenon is known as sewage sickness.

f) Disposal Guidelines

Parameters	Surface Water	Inland water	Marine water	Land
BOD	20	30	100	500
COD	250	250	250	---
SS	30	100	100	2100
pH	5.5-9	5.5-9	5.5-9	5.5-9

4. Preliminary Treatment





a) Racks and screens: same as water treatment part

b) Comminutors:

- or *shredders* are patented devices which break the large sewage solids to about 6mm in size. Such a device consists of revolving slotted drums, through which the sewage is screened, cutters mounted on drums, shear the collected screenings against a comb, until they are small enough to pass through 5mm to 10mm wide slots of drum.
- They are usually arranged in pairs to facilitate repair and maintenance. They should always be *preceded by grit chambers to prevent excessive wear.*

c) **Grit chamber**

- Grit chambers are designed to separate **heavier inorganic suspended particles** (size 0.15 to 0.20mm or more) by process of sedimentation from waste water and to pass forward lighter organic material.
- Many a time, grit chambers are aerated by *providing outside air through compressor*. The diffused air creates spiral currents which helps in settlement.
- **Aerated grit channels** are usually designed to provide detention period of 3 minutes at maximum flow rate. The air diffusers are located at 0.45m to 0.60m above the normal bottom of tank.
- **Detritus tank**: these are nothing but rectangular grit chambers, designed to flow with a smaller flow velocity (0.09m/s) and longer detention time (3 to 4 minutes) so as to separate out even fine sand particles. A large number of organic particles also settle which are latter separated from grit by control of currents in the tank through baffles, or by controlled aeration of the flow through tank.
- Generally, grit channels are designed to remove all particles of higher specific gravity of 2.65 or so, with a nominal diameter of 0.2mm and more, having settling velocity of about 21 mm/s (at 10°C). it is not at all desirable to remove any organic matter in the grit chambers, because no further treatment of removed grit is provided. The grit chamber must hence, be designed to scour the light organic particles, while the heavier grit particles remain settled.
- **DESIGN GUIDELINES**

- ◆ Surface area is determined on the basis of overflow rate (v_s).
- ◆ Detention time is usually 45 to 90 seconds.
- ◆ Bottom Scour (modified shields formula)
 - $v_c = 3 \text{ to } 4.5 \sqrt{g(G-1)d}$
- ◆ Settling velocity

$$v_s = \sqrt{\frac{4(G-1)gd}{3C_D}}$$

Find v_h and v_s
 For Q given
 $c/s \text{ area} = \frac{Q}{v_h}$
 assume height h find B
 detention time $t_d = \frac{h}{v_s}$
 length = $v_h \times t_d$

$Re < 0.5$	$d < 0.1mm$	$C_D = \frac{24}{Re}$	$v_s = \frac{(G-1)\gamma_w d^2}{18\mu}$
$0.5 < Re < 10^4$	$0.1 < d < 1mm$	$C_D = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34 \approx \frac{18.5}{Re^{0.6}}$	$v_s = \left[\frac{g(G-1)d^{1.6}}{13.88 v^{0.6}} \right]^{0.714}$
$10^3 - 10^4 < Re$	$d > 1mm$	$C_D = 0.4$	$v_s = 1.8\sqrt{gd(G-1)}$

- ◆ Hazen's Modified equation for settling in *transition zone* $0.1 < d < 1mm$

- $v_s = 60.6(G-1)d \left(\frac{3T+70}{100} \right)$

- Velocity control devices
 - ◆ **Proportional flow weir:** The Weirs, in which the discharge is proportional to head, are known as proportional Weirs. By float-regulated dosing devices the flow over a proportional weir can be controlled. When a rectangular cross section is required for grit channel proportional weir is provide, *Sutro weir* is a proportional weir.
 - ◆ **Parshall flume:** when parabolic cross section is used for grit channel. It is generally preferred over proportional weir as head loss is less.

d) Skimming tank:

- These tanks are provided for removal of oil and grease from the waste water which if not removed, hinders growth of microorganisms required for biological treatment. These tanks are provided before PST.
- Compressed air is passed from bottom of these tanks, rising bubbles of which coagulate oil and grease particle and carry them to surface of tank, where it is easily skimmed off.
- In order to **increase effectiveness of these tanks**, **chlorine gas may also be passed** along with compressed air, which destroys colloidal effect of enzymes that hold oil and grease particle in emulsified form.
- These tanks are not used in India, as coagulation of oil and grease does not take place at high temperature.
- **Vacuators:** grease can also be removed from sewage by vacuum floatation method, by subjecting the aerated sewage to a vacuum pressure of about 0-25cm of mercury for about 10 to 15 minutes.

e) Sedimentation tanks (PST)

- These are designed to remove a **part of the organic matter** from the sewage effluent coming out from the grit chamber.
- In complete sewage treatment, the sedimentation is carried out twice; once before and once after the Biological Treatment. When chemical coagulants are also used for flocculating the organic matter during the process of sedimentation, the process is called **chemical precipitation**.
- DESIGN PARAMETERS:
 - ◆ Overflow rate: also called surface loading or overflow velocity. It is discharge per unit plan area, is a very important term for design of continuous flow type settling tank. Theoretically speaking depth doesn't have any effect on the efficiency of sediment removal.
 - Normal values of overflow rates range between 40,000 to 50,000 l/m²/day for plain sedimentation tanks; and between 50,000 to 60,000 l/m²/day for sedimentation tanks using coagulants as aids; and about 25,000 to 30,000 l/m²/day for secondary sedimentation tanks.
 - ◆ Detention time (t): it is average theoretical time required for the sewage to flow through the tank. It is thus the time that would be required for the flow of sewage to fill the tank, if there was no out flow.

$$t_d = \frac{\text{Volume of tank}}{\text{rate of flow}}$$

$$= \frac{BLH}{Q}$$

- Detention time for a sewage sedimentation tank usually range between 1 to 2 hours. The lower value of 1hr detention period is generally adopted when the activated sludge treatment is used in secondary treatment after the sedimentation; and higher more normal value is used when trickling filters are used.
- ◆ Effective depth, excluding effective sludge zone, usually ranges between 2.4 to 3.6 m.

t_d	H	v_f	B	L/B	η_{ss}	η_{BOD}
2-2.5 hrs	2.5-3.5 m	0.3 m/min	5-6	4-5	60-70%	30-40%

- **Short circuiting** in sedimentation tank:

- ◆ For efficient removal of sediments in sedimentation tank, it is necessary that the flow is uniformly distributed throughout the cross-section. If currents on the other hand, permit a substantial **portion of water to pass directly through the tank without being detained for the intended time**, the flow is said to be short-circuited.
- ◆ The actual average time taken by a batch of water in passing through a settling tank is called **flow through** period, and is always less than detention period, which is corresponding to theoretical time. The ratio of flow through period to detention time is called **displacement efficiency**.
- ◆ $\eta_d \% = \frac{\text{flowing through period}}{\text{detention period}}$

Type I Discrete settling	It is type of settling where no change in shape, size and mass of particles occur during settlement, hence each particle settles as individual. Settling velocity can be computed using Stokes' law or transition law. Example: plain sedimentation, grit chamber.
Type II Flocculent settling	Shape, size and mass changes during settlement due to flocks getting attached. This is characteristic of particles having concentration of 1000mg/l . No mathematical relation exists for this case. Example: Settling in clariflocculator, PST
Type III Zone / hindered settling	It is type of settling when concentration is in intermediate range (1500-1800mg/l), such that particles are <u>not in physical contact</u> but their <u>velocity field overlaps</u> , resulting in settlement of particles in respective zones. Example: SST after Activated Sludge Process.
Type IV Compression settling	This type of settling takes place when concentration is high (2000mg/l), such that particles are in physical contact with each other. Weight of particle in upper layer is supported by weight of particle in lower layer. Any further settling takes place due to compression of solids accompanied by squeezing of water from the voids. Example: SST with trickling filter.

5. Biological Treatment

a) Trickling filter

- Working: NOT EXPLAINED HERE
- The design of trickling filter primarily involves the design of the dia of the circular filter tank, and its depth. The design is based upon the values of filter-loadings adopted for design:
 - ◆ **Hydraulic loading rate**: it is the total flow *including recirculation* applied on unit area of the filter in a day. Expressed in million liters per hectares per day.
 - ◆ **Organic loading rate**: it is the 5day 20°C BOD, excluding the BOD of the recirculant, applied per unit volume in a day. Also called volumetric loading rate. Expressed in Kg of BOD per hectare meter of filter media per day.
 - ◆ Efficiency of conventional filter and its secondary clarifier

$$\eta \% = \frac{100}{1 + 0.0044\sqrt{u}}$$

- u organic loading rate in $kg/ha-m/day$
- Recirculation and its use (High rate trickling filter)
 - ◆ Recirculation improves the operating results of filters because:
 - It allows continuous dosing of the filters, irrespective of the fluctuations in flow.
 - It equalizes and reduces loading, thereby increasing the efficiency of the filter.
 - It provides longer contact of the applied sewage with the bacterial film on the contact media.
 - The influent remains fresh all the time, and also helps in reducing odour and fly nuisance.
 - ◆ Efficiency of High rate filters

- It depends upon the volume of recirculated flow and also on organic loading rate.
- Recirculation factor represents the number of effective passages through the filters.

$$F = \frac{1 + R}{(1 + 0.1R)^2}$$

$$\eta_I \% = \frac{100}{1 + 0.0044 \sqrt{\frac{Q_o S_o}{VF}}}$$

- $Q_o S_o$ is total organic load in Kg/day, V in ha-m, R is re-circulation ratio $R = \frac{Q_r}{Q_o}$
- Efficiency of 2nd stage Trickling filter

$$\eta_{II} = \frac{100}{1 + \frac{0.0044}{1 - \eta_I} \sqrt{\frac{Q_o S_o (1 - \eta_I)}{V_2 F_2}}}$$

- DESIGN STEPS for standard rate filter
 - ◆ Use hydraulic loading to find Surface area
 - $area = \frac{Q}{HLR}$
 - $d = \sqrt{area \times \frac{4}{\pi}}$
 - ◆ Use organic loading rate to find volume
 - $volume = \frac{Q}{OLR}$
 - $depth = \frac{volume}{area}$
 - ◆ The filter dia and depth is designed for average value of sewage flow. The rotary distributors, under-drainage system, and other connected pipe lines are designed for peak flow and checked for average flow.
- Design steps for high rate trickling filter
 - ◆ Equate efficiency to find the Volume required
 - ◆ Assume depth between 1.2m to 1.8m to find area and diameter.
- Merits of trickling filter
 - ◆ Rate of filter loading is high, requiring lesser land area and smaller quantity of filter media.
 - ◆ Effluent obtained from trickling filter is sufficiently nitrified and stabilized. They can remove **75% BOD and 80% suspended solids**. The effluent thus can be disposed with smaller quantity of dilution.
 - ◆ Working of trickling filter is simple, and does not require any skilled supervision.
 - ◆ They are flexible in operation, and can withstand application of variety of sewage having different concentration and composition. Even if they are overloaded, they can recoup after rest.
 - ◆ They are self-cleaning, mechanical wear and tear is small, as they contain less mechanical equipment.
- Demerits
 - ◆ Head loss through these filters are high, cost of construction is high.
 - ◆ These **cannot treat raw sewage**, and primary treatment is a must.
 - ◆ These filters pose a number of **operational troubles** such as given below.
 - **Fly nuisance**: The filter fly, *psychoda*, which develops in the filter particles, may prove to be nuisance, as they can be carried away into the habitation. This problem may be controlled by flooding the filter with sewage for 24 hours or more. Another method is by using insecticides, such as DDT, chlordane, and benzene hexachloride.
 - **Odour nuisance**: odour, generally do not prevail in trickling filters using rotary distributors; but when fixed nozzles are used, H_2S and other odourous gases are

frequently released from sprays. The usual remedy is to chlorinate the sewage or by keeping the sewage fresh by recirculating as done in rapid filters.

- **Ponding trouble:** sometimes, voids in filter media gets clogged due to heavy growth of fungi and algae. This results in ponding of sewage over the filter bed. This can be controlled by chlorinating the sewage which kills the algae, thus causing unloading of accumulated material. Other method is to add copper Sulphate and rest the bed for some time.

- Recirculation improves the operating result of filter because of following reasons:
 - ◆ It allows for continuous dosing of filter, irrespective of fluctuations.
 - ◆ It equalizes and reduces the loading, thereby increasing the efficiency of filter.
 - ◆ Recirculation provides longer contact of the applied sewage with the bacterial film thereby seeding it with bacteria and accelerating the biological oxidation process.
 - ◆ The influent remains fresh all the time, helps in reducing odour and fly nuisance.

b) Activated Sludge Process

- Activated sludge process provides an excellent method of treating either **raw sewage** or more generally **settled sewage**.
 - ◆ Working NOT EXPLAINED here.
 - ◆ The effluent obtained from a properly operated activated sludge plant is of high quality, usually having a lower BOD than that of trickling filter plant. BOD removal is up to 80-95% and bacterial removal is up to 90-95%. Land area required is also quite less. In this process, a rather close degree of control is necessary in operation to ensure that ample supply of oxygen is present, intimate and continuous mixing occurs, and ratio of activated sludge to incoming sludge is kept constant.
- DESIGN considerations

Hydraulic Retention time or <i>aeration period</i>	$HRT = \frac{\text{Volume of tank}}{\text{rate of sewage inflow}} = \frac{V}{Q_o}$
Organic loading rate	<p>Volumetric BOD loading is BOD₅ load applied per unit volume of aeration tank</p> $OLR = \frac{Q_o S_o}{V}$
F/M ratio	<p>Food (F) to Micro-organism (M) ratio is a manner of expressing BOD loading with regards to microbial mass in the system.</p> $\frac{F}{M} = \frac{Q_o S_o}{VX}$ <p>➤ It is the main factor controlling the BOD removal. Lower the F/M ratio, the higher will be BOD removal. F/M ratio can be varied by varying MLSS concentration in the aeration tank</p>
Sludge age	<p>Also called, <i>mean cell residence time</i> or <i>solid retention time</i>, is an operational parameter related to F/M ratio. It may be defined as the average time for which particles of suspended solids remain under aeration.</p> $\theta_c = \frac{\text{total microbial mass in reactor}}{\text{mass withdrawn daily, wasted + effluent}} \approx \frac{VX}{Q_w X_u}$
Specific substrate utilization rate	$U = \frac{Q_o (S_o - S_e)}{VX}$
Oxygen required	$O_2 \left(\frac{kg}{day} \right) = \left[\frac{BOD_5 \text{ removed}}{0.68} - 1.42 \times \text{solid withdrawn} \right]$

- ◆ Under steady state operation, the mass of activated wastage sludge is given by:

MO going out = growing MO - dying MO

$$\Rightarrow Q_w X_u = \alpha_y \cdot Q_o (S_o - S_e) - k_d \cdot VX$$

$$\Rightarrow \frac{Q_w X_u}{VX} = \alpha_y \cdot \frac{Q_o (S_o - S_e)}{VX} - k_d \cdot \frac{VX}{VX}$$

$$\frac{1}{\theta_c} = \alpha_y U - k_d$$

- Growth yield coefficient $\alpha_y = \frac{\text{microbial mass synthesised}}{\text{mass of substrate consumed}}$
- k_d - microorganism decay coefficient

- Sludge characteristics

- ◆ **Sludge volume index:** this term is used to *indicate the physical state of sludge produced* in a

biological aeration system. It represents the degree of concentration of sludge in the system, and hence decides the rate of recycle of sludge required to maintain the desired MLSS and F/M ratio in the aeration tank to achieve the desired degree of purification. *It is defined as volume occupied in ml by 1gm of solids in mix liquor when allowed to settle for 30min.*

$$SVI = \frac{V_s (\text{ml/l})}{X_s (\text{mg/l})} \times 10^3$$

- MLSS in return sludge

$$X_u = \frac{10^6}{SVI} \text{ mg/l}$$

- Return sludge ratio

$$\frac{Q_r}{Q} = \frac{X}{X_u - X}$$

- For municipal sewage SVI is in the range of 80 to 150 ml/gm

- ◆ **Sludge density index**

- $SDI = \frac{100}{SVI}$

- ◆ **Bulking and foaming**

- Foam formation and poorly settling sludge are the two most common problems of activated sludge process. A sludge that exhibits poor settling characteristics is called **Bulking sludge**. Filamentous microorganisms have been found to be responsible for bulking of sludge.
- It can be controlled by reduction of sludge age to less than 6 days. And chlorination of returned activated sludge.

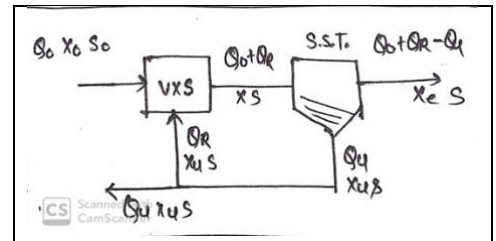
- ◆ **Rising sludge / blanket rising**

- It is a problem encountered in SST of an activated sludge plant caused by denitrification. Denitrification results in formation of *nitrogen gas bubbles* which lift up the settled sludge, thereby deteriorating the quality of clarified effluent.
- Nitrification in aeration tank leads to subsequent denitrification in SST, in order to avoid nitrification, sludge age is reduced by increasing the waster sludge discharge.

c) Modification of basic activated sludge process

- **Plug flow:**

- ◆ The basic activated sludge process, also called **conventional aeration process**, the recirculated activated sludge is added to the inlet end of the aeration tank as a single dose.
- ◆ The regime flow employed in the aeration tank is **plug flow**, which implies that the sewage moves down progressively along the aeration tank, essentially unmixed with the rest of the tank contents.
- ◆ It employs a long and narrow configuration of aeration tank with length equal to 5 to 50 times the width.



- ◆ The oxygen demand at the head of the aeration tank is high and then tapers down. However, the air is supplied at uniform rate, this leads to inefficiency.
- ◆ This system is always preceded by PST.
- ◆ It can be used for plants having capacity greater than 300MLD. Operational stability of this process w.r.t. shock loading is comparatively less, as there is no provision of mixing in it. F/M ratio and oxygen demand varies along the length. The BOD removal is 85-92%.
- ◆ The main limitations of conventional system are: (i) aeration tank volume requirement is high. (ii) lack of operational stability
- ◆ In order to overcome such difficulties posed by a conventional system plant, and meet specific treatment objectives, several modifications of conventional system have been suggested by modifying the process variables.
 - Complete mix
 - Extended aeration (Oxidation ditch)
- **Complete mix:**
 - ◆ This is used for *smaller plants* having capacity less than 25MLD.
 - ◆ In this process complete mixing of incoming activated sludge with waste water is done mechanically. This increases the opportunity of contact between the two, increasing the rate of removal.
 - ◆ Complete mix plant possesses capacity to hold much higher MLSS concentration level in aeration tank (3000-4000 mg/l as against 1500-3000 mg/l of conventional plant). This helps in adopting smaller volume for aeration tank.
 - ◆ The plant has increased operational stability at shock loadings, and also increased capacity to treat toxic biodegradable wastes like phenols.
 - ◆ Square or circular tank fitted with mechanical aerators are used in this case. Operational stability is more as homogeneous environment is created by shock loading.
- **Oxidation ditch:**
 - ◆ The conventional activated plant has been modified to *eliminate the PST* and *sludge digestion* tank, in a process called **extended aeration**. Which aims at providing an aeration tank with a longer aeration time.
 - ◆ Each ditch channel is equipped with a special type of horizontal axis rotor, which serves the purpose of agitating and circulating the sewage, and thereby oxygenating them. The quality of effluent obtained is quite good, with suspended solids removal at about 95% and BOD removal at about 98%. Power cost is more but compensated by elimination of PST and digestion tank. The method however, requires skilled supervision.
- **Contact stabilization:** also called as **biosorption process**. BOD removal takes place in two steps. This process is designed for treating colloidal waste water.
 - ◆ **Contact tank:** sewage and returned sludge is mixed and aerated for a comparatively shorter time period of 0.5 to 1.5 hrs. in a special mixing tank called contact tank. This mixing allows the suspended and dissolved organic matter to be sorbed on activated sludge flocs, which is further allowed to settle in SST.
 - ◆ **Stabilization tank:** the settled sorbed organics and flocs are then transferred to sludge aeration tank (aerodigester), where they are stabilized for 3 to 6 hrs. before getting fed back to contact aeration tank.
 - ◆ It has greater capacity to handle shock loading, also has greater resistance to toxic substances. Air requirement is same as conventional process, but the tank volume is reduced to half. Total aeration time is reduced thereby increasing plant capacity. This process has found application in medium sized plants with capacity up to 40 MLD.
- d) Rotating Biological contractor
 - It has been recently developed and does not fit precisely in activated sludge or trickling filter category, but does employ principle common to both of them.

- RBC is a cylindrical media made of closely mounted thin flat circular plastic sheets or discs of 3 to 3.5m in diameter, 10mm thick and 30 to 40mm spacing, mounted on a common shaft.
- They are usually made up to 8m length, and placed in series or parallel. Disc are kept immersed **40% of their diameter** and are rotated around their central horizontal shaft at a speed of 1-2 rpm.
- This process offers very high degree of treatment up to nitrate level.

e) Oxidation Pond

- Also called stabilization ponds are open flow-through earthen basins specifically designed and constructed to treat sewage and biodegradable industrial wastewaters.
- Such ponds provide comparatively long detention periods, from few days to several days, during which the wastes get stabilized by the action of natural forces.
- Detention time

$$t_d = \frac{1}{K_d} \log_{10} \left\{ \frac{L_o}{L_o - L_r} \right\} \text{ days}$$

- ◆ L_o – BOD of effluent entering the pond. L_r – BOD removed

• DESIGN Considerations

- ◆ Surface area depends upon the amount of oxygen that can be produced by photosynthesis, which depends on latitude of pond site, its elevation from MSL, and sky clearance. Suitable value of organic loading may range from 300 – 150kg/ha/day for hot tropical countries like India; 90 – 60kg/ha/d for colder countries.
- ◆ Each unit may have an area ranging from 0.5 to 1ha. It is desirable to have multiple ponds in series or parallel configuration.
- ◆ Detention time can be calculated according to % removal $k_d = 0.1 \text{ day}^{-1}$ at 20°C
- ◆ Find $Volume = Qt_d$
- ◆ Find depth $d = \frac{V}{A}$, optimum range (1-1.5m), free board of 1m may also be provided.
- ◆ INLET and OUTLET design
 - For the flow assume 8hr flow, and compute discharge in m³/s from MLD.
 - Find the assumed velocity (0.3m/s to 0.9m/s) compute area required for inlet and ϕ
 - The outlet dia will be 1.5 times the inlet diameter.
- Effluent from these ponds are comparatively rich in nutrients hence reutilized in sewage farming. Overloading of pond may result in odour problem which is avoided by adding sodium nitrate that acts as an oxidizing agent and nutrient for algae.

f) Septic tank (*anaerobic decomposition*)

- A septic tank may be defined as a primary sedimentation tank, with a longer detention time (12 to 36 hours, against 2 hours), and with *extra provision for digestion of the settled sludge*.
- It admits raw sewage, and remove about 60-70% of the dissolved matter from it. The effluent is sufficiently foul in nature, and disposed of in soak pits.
- These are generally provided in areas where sewers have not been laid and for catering to the sanitary disposal of sewage produced from isolated communities, schools, hospitals, hotels, other public institutions, etc.
- DESIGN Consideration

It is designed as ordinary sedimentation tank with following data:

➤ Capacity (V) of septic tank:

The volume of liquid which a septic tank can accommodate is called capacity. A septic tank should be capable of storing the sewage flow during the detention period (24hrs), and an additional volume of sludge for 6 months to 3 years, depending upon the periodicity of cleaning.

Sewage flow (only water closets)	40-70 l/c/day
Sewage flow (sullage included)	90-150 l/c/day
Rate of accumulation of sludge	30 l/c/year

Free board	0.3-0.5 m
Detention period	12 to 36 hrs (24 hrs)

- Disposal of Effluent from septic tank
 - ◆ The effluent coming out from septic tank contains large amount of putrescible organic matter and its BOD is quite high. This effluent should, therefore, be disposed of carefully, so as to cause minimum nuisance or risk to health of people.
 - ◆ Soil absorption system is a method of disposal, which involves the disposal of effluent on land, and can be adopted only when sufficient land is available and soil is sufficiently porous as to give a percolation rate not exceeding 60 minutes.
 - ◆ **Percolation rate**: is time required in minutes for seepage of water through ground by 1cm. higher percolation rate naturally reflect less porous soil.
 - ◆ Soil absorption system is of following two types:
 - **Soak pit**: $t < 30\text{min}$, a soak pit is a circular covered pit, through which the effluent is allowed to be soaked or absorbed into the surrounding soil. For disposal in soak pits the underground soil should be highly porous with percolation rate not exceeding 30 minutes.
 - **Dispersion trench**: $30\text{min} < t < 60\text{min}$, in this method septic tank effluent is allowed to enter into a masonry chamber called distribution box, from where it is uniformly distributed through an underground network of open jointed pipes into absorption trenches called dispersion trenches.
 - ◆ Surface area required: the minimum area of the pit or trench required, shall be worked out on the basis of the *maximum allowable rate* of effluent application, which can be computed by empirical equation

$$\frac{Q_{\max}(\text{l/day})}{A(\text{m}^2)} = \frac{204}{\sqrt{t_{\min}}}$$

- t – standard percolation rate in minutes

g) Imhoff tank

- It is an *improvement* over septic tank, in which the incoming sewage is not allowed to get mixed up with the sludge produced, and the outgoing effluent is not allowed to carry with it, large amount of organic load, as in the case of a septic tank.
- It is a two storied tank in which sedimentation is carried out in upper sedimentation chamber and digestion in lower digestion chamber.

h) Up flow anaerobic sludge blanket reactor (UASB):

- In this process, waste water is passed through a layer of activated sludge, vertically upward, due to which micro-organism present in it comes in contact with organic matter leading to decomposition. As no mixing is induced in the process, stratification of constituents takes place in it.
- This method is suitable for both treatment of soluble waste water and **waste water having particulate matter**.

i) Secondary sedimentation tank

- For Trickling filter
 - Biological treatment does remove only a very small percentage of finely divided suspended organic matter, while majority of organic matter undergoes a change of character. Organic solids are converted into coagulated suspended mass, which is heavier and bulkier, and settles down by gravity. The effluent of filter is, therefore, passed through a sedimentation tank, called the secondary clarifier or secondary settling tank or *Humus tank* (only SST for trickling filters are said so).
- For activated sludge process
 - Solids in SST are considerably light in weight, hence are significantly affected by the turbulence and current of the outgoing effluent, hence in order to prevent the loss of solids out from the tank, sufficient length of overflow weir is provided along the circular tanks.

Weir loading rate, not exceeding 150 m³/day/m of weir is provided, this value is based on average flow of sewage and not to mixed liquor flow.

- Solid loading is another important factor, which governs the design of secondary basin, as in the secondary basin hindered settling occurs. The solid loading rate based on mixed liquor flow to the settling tank may be kept at 100-150 kg/m²/day at average flow, should not exceed 250 kg/m²/day at peak flow. Such rates ensure adequate sludge thickening and concentrated sludge returns.
- The surface area of ASP settling tank should be *designed for both overflow rate and solid loading rate* and larger value is adopted.

6. Digestion and disposal of Primary and Secondary sludge

a) Sludge characteristics

- The sludge which is deposited in PST is called **raw sludge** and the sludge deposited in SST is called secondary sludge.
- Raw sludge is odorous and contains highly putrescible organic matter and is, thus very objectionable. Secondary sludge is putrescible but less objectionable.
- In addition to perfectibility of sludge, another problem posed by the sludge is its **high moisture content**.
 - ◆ In case of Raw sludge, it is 95%
 - ◆ 2^o sludge from trickling filter 96 to 98%
 - ◆ 2^o sludge from activated sludge process 98 to 99%
- Sludge containing high moisture content becomes bulky and difficult to handle.

% w	Solids	Sludge	Sludge per kg of solids	Remark
90%	10	100	10	
95%	5	100	20	This sludge is 2 times bulkier than 90%
99%	1	100	100	This sludge is 5 times bulkier than 95%

b) Sludge digestion

- In anaerobic sludge digestion sludge gets broken into three forms
 - ◆ **Digested sludge**: it is a stable humus like solid matter, black in colour and with reduced moisture content and is therefore having, reduced volume (about 1/3 times of undigested volume).
 - ◆ **Supernatant liquor**: it includes liquified and finely divided solid matter, and is having high BOD (about 3000ppm). It is re-treated with raw sewage.
 - ◆ **Gases of decomposition**: gases like **methane** (65 to 70%), **carbon dioxide** (30%), and traces of other inert gases like *nitrogen, hydrogen sulphides etc.* are evolved. They may be collected, particularly methane which has a high calorific value and used as a fuel.
- Three distinct stages have been found to occur in the biological action involved in the natural process of sludge digestion. These stages are:
 - ◆ **Acid fermentation**: or acid production stage, in this first stage of sludge digestion, the fresh sewage-sludge begins to be acted upon by anaerobic and facultative bacteria, called **acid formers**. These organisms solubilize the organic solids through **hydrolysis**. The soluble products are then fermented to volatile acids and organic alcohols of low molecular weight. Gases like methane, carbon dioxide and hydrogen sulphides are also evolved. Intensive acid production makes the sludge *highly acidic*, and lowers the pH value to less than 6. Highly putrefactive odour are evolved during this stage, which continues for about 15 days. BOD of sludge increases to some extent during this stage.
 - ◆ **Acid regression**: in this intermediate stage, the volatile organic acids and nitrogenous compounds of 1st stage are attacked by bacteria to form acid carbonates and ammonia compounds. Decomposed sludge is very offensive, which entraps gases of decomposition and

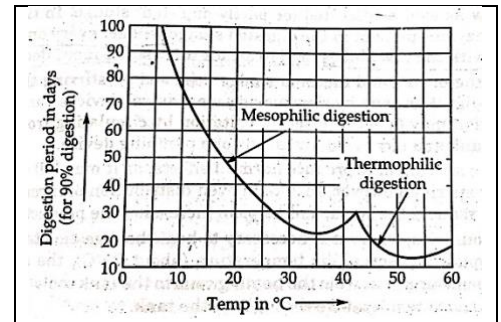
becomes foamy and rises to the surface to form scum. This stage continues for a period of about 3 months. BOD is high even during this stage.

- ◆ **Alkaline fermentation:** in this final stage of sludge digestion, more resistant materials like proteins and organic acids are attacked and broken by anaerobic bacteria called **methane formers**. The liquid separates out from solids, and the digested sludge is formed, which is granular and stable, and does not give offensive odour. It has musty earthy odour. Digested sludge is alkaline in nature. Large volumes of **methane gas** along with small amount of *carbon dioxide* and *nitrogen*, are evolved. The BOD of sludge rapidly falls down during this stage.

- Factors affecting sludge digestion

- ◆ **Temperature:** rate of digestion is generally more at higher temperature.

- **Zone of thermophilic digestion:** in this zone of high temperature, digestion is brought about by heat loving thermophilic organisms. The temperature in this zone ranges between 40° to 60° C. This zone **is not employed** due to odour problem and operational difficulties.
- **Zone of mesophilic digestion:** In this zone of moderate temperature, digestion is brought about by common mesophilic organisms. The temperature in this zone ranges between 25 to 40°C. the digestion period can be brought down to about 30 days.



- ◆ **pH value:** volatile organic acids formed in the intermediate stage of digestion, are converted to methane gas by a specialized group of strictly anaerobic and slow growing bacteria, called methane formers. *If methane formers are not operating properly, an accumulation of volatile acids may occur*, causing the pH to drop to a value as low as 5, which will suppress further bacterial action.
- ◆ **Seeding with digested sludge:** when first put in operation, it is highly beneficial to seed the tank with digested sludge from another tank. Without seeding, it may take a few months to get a tank operating properly.
- ◆ **Mixing and stirring of raw sludge:** incoming raw sludge should be thoroughly mixed with digested sludge, so as to make a homogenous mass of raw as well as digested sludge.
- **Oil and grease** if present in the sludge rise to the surface and leads to formation of scum layer that serves the following purpose:
 - ◆ It acts as a thermal insulator, thereby helps in increasing the temperature during digestion.
 - ◆ It avoids the release of gases (H_2S) during digestion, thereby maintaining sanitary condition around digester.
- Nuisance causing bacteria

- ◆ These are those bacteria which reduces Sulphate to sulphides, that is disastrous for methane formers. Hence to avoid them iron is added which precipitates out sulphides as FeS.

c) Sludge Digester construction details

- It consists of a circular RCC tank with hopper bottom and having a fixed or floating type roof.
- The raw sludge is pumped into the tank, seeded on first operation.
- The gases of decomposition are collected in a gas dome.
- The digested sludge which settles down to the hopper bottom is removed under hydrostatic pressure, periodically, once a week or so.
- The supernatant liquor lying between the sludge and scum is removed at suitable elevations, being high in BOD and suspended solids contents, is sent back for treatment along with raw sewage in the treatment plant.

d) DESIGN consideration

- Standard rate digester: when only one tank is provided. For *parabolic* decomposition capacity required:

- ◆ Volume

$$V = \left(V_i - \frac{2}{3}(V_i - V_d) \right) t_d + V_d t_s$$

- V_i – Volume of raw sludge fed per day.
- V_d – Volume of digested sludge withdrawn per day
- t_d – Digestion time in days
- t_s – Monsoon storage in days

- ◆ $V = \left(\frac{V_f + V_d}{2} \right) t_d + V_d t_s$ if linear variation is considered, which gives larger value so used for conservative design.

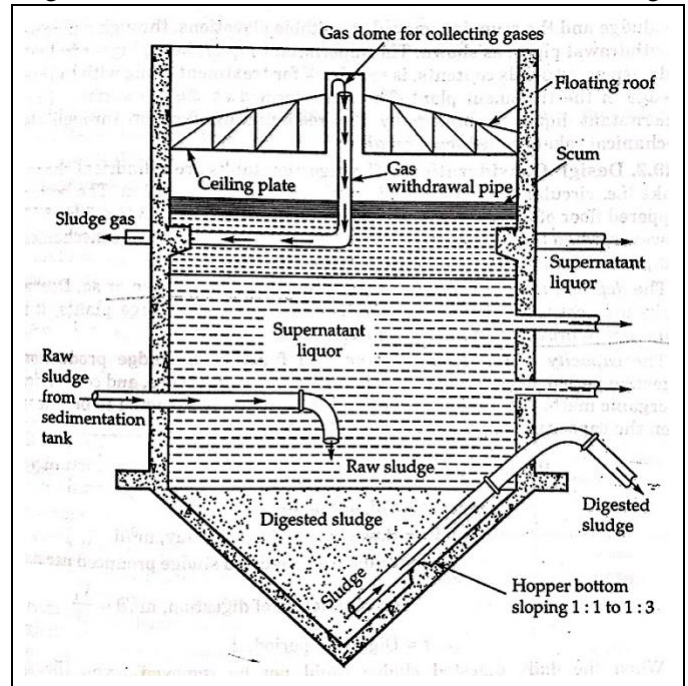
- High rate digester: two tanks are provided one for mixing and other for separation.

- ◆ $V_1 = V_f t_h$

- ◆ $V_2 = \left(V_f - \frac{2}{3}(V_f - V_d) \right) t_d + V_d t_s$

e) Rural sanitation

- Removable receptacle privy
- *Bore-hole privy*: this type of latrine consists of 40cm dia bore hole, normally drilled 4 to 6m deep but 1m above water table. Biggest drawback of this type of latrine is that, bore hole gets filled up after sometime, and new bore hole will be needed requiring shifting of the entire superstructure.
- *Concrete vault privy*: this is an improvement from a bore hole privy, for areas of high water-table or in sandy soils. To prevent bad odour, generally soil is thrown daily after use.
- *Aqua privy*: (wet latrines) dry latrines, described above, are either temporary in nature or need frequent cleaning. The aqua privy, on the other hand, is an improved form of privy, and is a permanent arrangement. These have three interconnected underground masonry chambers.
- *Sulabh shauchalaya*: (hand flush water seal latrine) such a latrine is considered to be a better choice than a septic tank latrine, since it neither involves periodic manual cleaning as is involved for a septic tank, nor it emits foul orders as are emitted by the vent pipe of a septic tank.



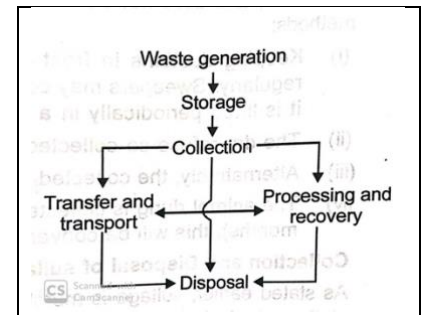
III. Solid waste Treatment

a) Definitions

- Solid waste management (MAINS)

- ◆ It is the discipline associated with the control of *generation, storage, collection, transfer and transport, processing and disposal* of solid waste in a manner that is in accord with the best principles of *public health, economics, engineering, conservation, aesthetics* and other environmental considerations. Functional elements of waste management includes:

- **Generation:** for an effective SWM to work, a good idea about the activities and the sources generating waste is essential, it will give the quality and composition of waste produced, and method of reduction of waste at the source can be thought of.
- **Storage:** it is the 2nd key element because collection of wastes never takes place at the source or at the time of their generation, so waste need to be stored onsite.
- **Collection:** this includes gathering of wastes and hauling them to location where, it will be either transferred, processed or disposed.
- **Transfer and transport:** it involves transfer of wastes from smaller collection unit to larger ones for transportation over long distances.
- **Processing:** is done to alter physical and chemical characteristics of waste for energy , resource recovery and recycling.
- **Disposal:** it is the last stage of SWM where the type of method of disposal is selected according to the type of waste combined with land, environment and climatic consideration.



- The municipal solid waste is a heterogeneous mixture of various kinds of solid wastes. It is generated through domestic and commercial activities and is also called **refuse**.

Garbage 45%	<ul style="list-style-type: none"> ➤ This includes all sorts of putrescible (<i>bio-degradable</i>) organic wastes obtained from kitchens, hotels, restaurants etc. ➤ All the waste food articles, vegetable peelings, fruit peelings, etc. are thus, included in this term. These wastes are organic in nature, and thus, likely to decompose quickly, producing foul odour and health hazards. ➤ The density of garbage usually varies between 450 to 900 kg/m³.
Rubbish 15%	<ul style="list-style-type: none"> ➤ It can include a variety of materials, which may either be combustible (such as paper, plastic, textile, etc.) or incombustible (such as broke glass, crockery, masonry, etc.) ➤ Most of these types of wastes are discarded on a regular basis from homes, offices, and small commercial establishments. ➤ The density of rubbish usually varies between 50 to 400kg/m³
Incombustible ashes 15%	<ul style="list-style-type: none"> ➤ From household hearths, ashes, are also included in MSW, although its quantity is reduced in modern days. ➤ The density of ashes generally varies between 700 to 850 kg/m³
Street sweepings 25%	<ul style="list-style-type: none"> ➤ MSW may also include the fine dust, silt and sand, obtained from street sweepings.

b) Collection and transportation of MSW

- In India, the refuse is generally collected in individual houses in small containers, and from there, it is collected by sweepers in small hand-driven carts, and then dumped into the masonry chambers constructed by the municipalities along roadsides. The refuse is finally carted away by municipal trucks, for further disposal during some day time.
- The method adopted here are highly unsatisfactory, and need tremendous improvements and changes.

c) Disposal of MSW

- Sanitary land filling
- Shredding and pulverization

- Composting including vermicomposting
- Incineration and thermal pyrolysis
- Barging it out into the sea

d) Sanitary land fill

- In this method of refuse disposal, refuse is carried and dumped into low laying area, under an engineered operation, designed and operated in an environmentally sound manner.
- In this method, the refuse is dumped and compacted in layers of about 0.5m thickness, and after a day work, when depth of filling becomes about 1.5m, it is covered by good earth of about 15cm thickness, called **daily cover**.
- The filling of refuse is done by dividing the entire land-fill area into smaller portions, called cells. These cells are initially filled with daily compacted refuse of about 1.5m depth. After filling all the cells with first lift, the second lift is laid in about 1.5m height, and covered with good earth cover of 0.15m depth, called **intermediate cover**. The process continues till the top most lift is piled up, over which the **final cover** of good earth of about **0.6m** depth is laid and compacted to prevent rodents from burrowing into the surface.
- **Cap-system:**
 - ◆ or the cap, is usually provided at the top of sanitary land fill, to avoid formation of leachates. It consists of following layers. 45 cm thick compacted clay layer is provided at the bottom, overlain by 15 cm thick drainage layer consisting of sand, above it is laid a geotextile filter membrane to protect the drainage layer from being clogged. Finally, 30cm thick soil layer is laid at the top to promote vegetative cover and grassing.
- The refuse, in managed landfills, may usually get stabilized, within a period of 2 to 4 months, and settle down by 20-40% of its original height.
- For optimum decomposition moisture content in the refuse must be greater than 60%.
- **leachate**
 - ◆ Dumped garbage contains harmful and sometimes carcinogenic non-bio-degradable substances, such as plastics, unused medicines, paints, insecticides, sanitary napkins etc., causes production of *leachate*, when excess seeping water comes out of the dump.
 - ◆ Under normal conditions in hazardous landfills leachate is found at the bottom of landfill. From there, it percolates through the underlying soil strata of the landfill and pose inherent risk of polluting the ground water.
 - ◆ To elevate this problem, it is always better to either eliminate the production of leachate, or to collect and treat it separately.
 - To eliminate the production of leachates, surface water is stopped from entering the landfill by providing an impervious clay layer over the top of the fill at a decent slope with adequate drainage.
 - Under-drainage pipes can be laid to collect the leachates before it penetrates further below.
 - Sealants: clay, vinyl chloride, butyl chloride, Asphalt, Bitumen
- Methods used for landfilling

Area method	<ul style="list-style-type: none"> ➤ It is used when terrain is unsuitable for trench excavation especially when the water table is high. ➤ Entire land fill site is divided into number of sub-areas by constructing embankments and roads. ➤ Filling operation is started by building an earthen levee against which wastes are placed in layers and compacted. At the end of each day cover material is placed over the compacted fill. A final layer of cover material is used when the fill reaches the final design height.
Trench method	<ul style="list-style-type: none"> ➤ It is ideally suited to areas where an adequate depth of cover material is available at the site and where the water table is well below the surface.

	<ul style="list-style-type: none"> ➤ A trench is excavated and then filled with waste cells of daily waste, separated by the earth cover, as described in area method. ➤ The earth excavation from trench can be used to provide daily cover as well as final cover on the waste fillings.
Depression method	<ul style="list-style-type: none"> ➤ At locations where natural or artificial depressions exist, it is often possible to use them effectively for land filling operations. ➤ The techniques to place and compact solid waste in depression landfills vary with the geometry of site, the characteristics of the cover material, hydrology and geology of the site and the access to the site.

e) Composting

- Composting of refuse is a biological method of decomposing solid wastes. This decomposition can be affected either under aerobic or under anaerobic conditions, or both. The final end product is a *manure*, called *humus*. In India composting is practiced in rural areas on the mixture of night soil and refuse. Two methods are generally adopted here:
 - ◆ **Indore process:** it uses manual turning of piled up mass, for its decomposition under aerobic condition. In this method layers of vegetable wastes and night soil are alternatively piled in depths of about 7.5 to 10 cm each, to a total depth of about 1.5m in a trench or above the ground to form a mound called *windrow*.
 - The moisture content of the turning mass is maintained at about 55% for getting optimal decomposition of the waste mass.
 - Entire composting gets completed in 3-4 months; volume reduction of the original organic material is 50% under ideal conditions.
 - ◆ **Bangalore process:** it involves anaerobic decomposition of wastes and does not involve any turning or handling of the mass and is hence cleaner than Indore method. Refuse and night soil are piled up in layers in an underground earthen trench with top covered by layer of earth of 15 cm depth.
 - After 4 to 5 months, the refuse gets fully stabilized and changes to brown colored odourless powdery mass, called humus.
 - The initial C-N ratio and moisture content of the compost heap are the two important controlling factors in the success of anaerobic digestion, which finally produces a compost free from pathogens.
- **Optimum C/N ratio: 30-50**
 - ◆ Bacteria use nitrogen for building their cell structures (as proteins) and carbon for food (as energy). The anaerobic bacteria, developing in this digestion use up carbon about 30-50 times faster than they use up nitrogen. Hence C/N should be 30-50 times for optimum digestion.

However, when there is <i>too much carbon</i> , CN ratio is more, nitrogen will be used up and carbon left over, thereby leaving the <i>digestion incomplete</i> . microorganism <i>growth remains incomplete</i>	Similarly, when there is <i>too much nitrogen</i> , C/N ratio is less, the carbon will soon get exhausted and fermentation stop, leaving nitrogen in digester, which will combine with hydrogen to form ammonia (NH ₃). This can <i>kill or inhibit the growth of bacteria</i> , especially methane producers
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- **Vermi-composting:** it uses natural composting process of decomposition of biodegradable organic matter by soil bacteria, but takes assistance of *cultured earth worms*. These earth worms help in quicker decomposition of organic matter.

f) Incineration and thermal pyrolysis

- Burning of refuse at high temperature in furnace, called incinerators, is a *sanitary method* of refuse disposal, and is widely adopted in developed countries like USA.
- Besides, being useful for burning city refuse, they are also quite helpful for burning the *hazardous solid* and liquid wastes of the hospitals and industries.

- **Thermal pyrolysis** is the burning of refuse in the presence of very sparse air or oxygen so that wastes do not completely burn, but only smolder to produce charcoal like product. In contrast to the combustion process which is highly exothermic, the **pyrolysis is highly endothermic**, that is why this process is also known as destructive distillation.
- g) Pulverization and shredding
- In real terms these are not the method of disposal of refuse, these are simply used to convert the heavier solids into lighter ones so as to carry out their effective disposal by any other methods.
 - Shredding refers to the actions of cutting and tearing; whereas, pulverization refers to the actions of crushing and grinding.
 - They not only help in reducing the volume of MSW, but also helps in changing the physical character of the waste, which becomes practically odourless and unattractive to insects.
- h) Autoclaving
- It is a low heat thermal process used for disposal of **bio medical waste**, in which steam under controlled temperature and pressure is passed over it to carry out its disinfection. After autoclaving the wastes, they are shredded and disposed of suitably.
 - **Hydroclaving**: it is an innovation over autoclaving. Here, indirect heating is done by providing steam into the outer jacket of a double walled container, while the waste inside the container is turned on by a suitable mechanism.

IV. Air pollution

a) Introduction

- Definition: (OECD) “*Air pollution is the presence of contaminant or pollutant substances in the air that do not disperse properly and that interfere with human health or welfare, or produce other harmful environmental effects.*”
- Natural and Man-made air pollution
 - ◆ Natural: events like volcanoes—which release huge amounts of ash, dust, Sulphur and other gases into air; forest fire— occasionally be caused by lightening; may cause air pollution. But these events occur very infrequently, so their contribution to air pollution is generally ignored.
 - ◆ Air pollution caused by human activities, such as burning of fossil fuels, intentional burning of forests to clear land for urbanization or agriculture, etc. tend to stay longer in atmosphere and may even lead to permanent atmospheric changes. Man-made release of air pollutions is an ongoing continuous phenomena on daily basis.
- All the pollutants which are emitted directly from identifiable sources either from natural events like dust storms, volcanos etc. or human activities like burning of wood, coal, oil; are called **primary pollutants**.
- These primary pollutants often react with one another or with water vapour, aided and abetted by the sunlight, to form entirely a new set of pollutants called **secondary pollutants**. These new pollutants are often more harmful than the original basic chemicals that produced them.

Primary	Secondary
<ul style="list-style-type: none"> •CO, CO₂ •SO₂, SO₃ •NO, NO₂ •Hydrocarbon •Pb •H₂S, H₂F •ethyl mercaptan and methyl mercaptan •Particulate matter 	<ul style="list-style-type: none"> •H₂SO₄ •O₃ •Formaldehyde •PAN peroxy acyl nitrate

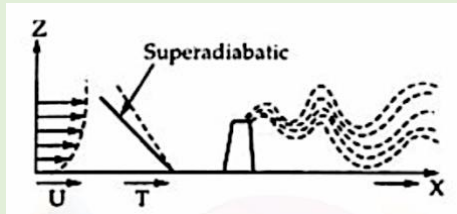
- Sulphuric acid is formed by simple chemical reaction between Sulphur dioxide and water vapour and is much more toxic pollutant than SO₂. Ozone, formaldehyde, PAN, are formed by photochemical reactions, caused by sunlight between two primary pollutants.

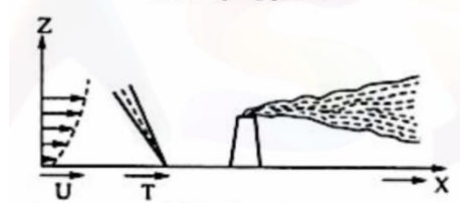
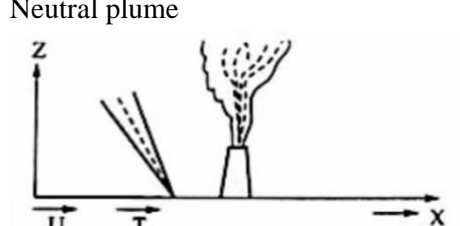
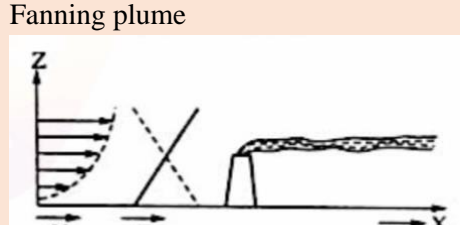
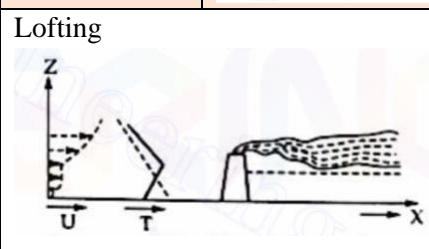
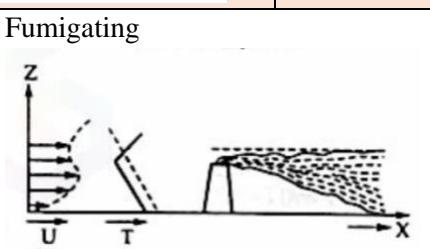
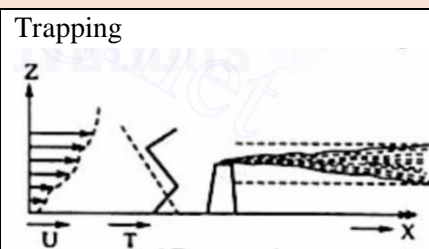
Oxides of Sulphur	<ul style="list-style-type: none"> ➤ It is an <i>irritant</i> gas, and when inhaled, affects <i>mucous membranes</i>. ➤ It increases <i>breathing rate</i> and causes <i>oxygen deficits</i> in body leading to bronchial spasms. ➤ It gets converted to sulphuric acid, which is a very strong corrosive acid. It is also responsible for acidity in fogs, smokes and rains, hence major source of corrosion of buildings and metallic objects. ➤ Its major sources are refineries and chemical plants, smelting operations, burning of fossil fuels, thermal power plants, open burning of garbage and municipal incineration plants.
Carbon monoxide	<ul style="list-style-type: none"> ➤ It is a colourless odourless and toxic gas, produced when organic materials like natural gas, coal, or wood are <i>incompletely burnt</i>. ➤ When inhaled CO replaces oxygen from hemoglobin and forms carboxy-hemoglobin, which reduces the oxygen carrying capacity of blood causing symptoms like <i>headache</i>, <i>dizziness</i>, reduction in reaction time. Higher level of CO inhalation may cause nausea, heart palpitation, difficulty in breathing.
Oxides of nitrogen	<ul style="list-style-type: none"> ➤ Atmospheric nitrogen may combine with oxygen at higher temperatures, as generated during fuel combustion, to form nitric oxide (NO), it is relatively harmless at low levels, but may cause <i>asphyxiation and respiratory discomfort</i>. ➤ Further oxidation causes formation of nitrogen dioxide which again is very harmful compound, as it is responsible for causing eye and nasal irritations, respiratory discomforts and even deaths. ➤ Oxides of nitrogen originates into atmosphere from automobile exhaust, incineration plants, furnace smokes etc. all involving high temperature due to combustion of fuel.
Hydrocarbons	<ul style="list-style-type: none"> ➤ They are either evaporated into the atmosphere from petroleum fuel supplies or are emitted out in automobile exhausts as fuels that did not burn. ➤ Hydrocarbons are washed out of air when it rains, and runs into surface water. Their presence in water causes an oily film on the water surface. ➤ At high concentrations they may cause irritation of eyes and respiratory tracts.
Suspended particulate matter	<ul style="list-style-type: none"> ➤ The particulate matter in air may occur largely in solid form as particles of dust, smoke, fume; also, in liquid form as mist and fog. ➤ The particles larger than a molecule but small enough to remain suspended in air are called <i>aerosols</i>. ➤ Small particulate matters can reach lungs and can damage lung tissues, causing diseases like asthma, bronchitis and even lung cancer. ➤ PM_{2.5} is more harmful than PM₁₀ for the fact that PM_{2.5} reaches much deeper into lungs than PM₁₀.
Lead	<ul style="list-style-type: none"> ➤ It is emitted by vehicles. Leaded petrol is the primary source of air-borne lead emission in Indian cities. ➤ High lead exposures can cause seizures, mental retardation and behavioral disorders. Infants are especially susceptible to low doses, resulting in disorders of <i>central nervous system</i>.
Carbon dioxide	<ul style="list-style-type: none"> ➤ Combustion of coal, petrol and diesel. Increasing concentrations over the years cause greenhouse effect, leading to global warming and climate change.
Ozone	<ul style="list-style-type: none"> ➤ It is a secondary pollutant produced by photochemical pollution, being the largest constituent of photochemical smog along with PAN. ➤ Ozone reduces lung function and is associated with coughing, sneezing, chest pain and pulmonary congestion.

b) **Photochemical smog** and production of PAN and ozone:

- Smog is a mixture of smoke and fog. It can be of two types; photochemical and coal induced.
- Atmospheric condition favourable for formation of photochemical smog are:

- ◆ Presence of high concentrations of hydrocarbons (HC) and nitrogen oxides (NO_x) in atmosphere.
 - ◆ Air stagnation, as not to cause dispersal of air pollutants.
 - ◆ Abundant sunlight.
 - The formation of photochemical smog is restricted to highly motorized cities, and it was first observed in Los Angeles (USA) in mid 1940.
 - $\text{HC} + \text{NO}_x + \text{H}_2\text{O} + \text{sunlight}$ gives rise to formation of *peroxy-acetyl-nitrate*. The main constituents are nitrogen oxide, PAN, hydrocarbons, carbon monoxide and large quantity of ozone.
 - While PAN in itself is an extremely harmful gas, the ozone gas is also quite harmful to respiratory system. At concentration of about 0.3ppm, cough and chest discomfort is increased.
- c) Dispersion of air pollutants into atmosphere
- Environmental lapse rate (ELR):
 - ◆ In the troposphere, the temperature of the ambient air normally decreases with an increase in the altitude. This rate of change of temperature is called lapse rate. This rate differs from place to place and from time to time.
 - Adiabatic lapse rate (ALR):
 - ◆ The rate at which the temperature decreases, as the parcel of pollutant gains height, may be considerably different from the ELR of the air through which the smoke parcel moves. The internal decrease of temperature (cooling) with height, which occurs in the rising parcel of air mass, can be theoretically calculated, by assuming the cooling process to be **adiabatic**. i.e. a process occurring without the addition of outside heat or loss of its own internal heat. Using conservation of energy and gas law this rate is mathematically calculated as **9.8°C per Km for dry air**. (6°C per Km for wet air)
 - ◆ Depending upon the ELR and ALR stability of atmosphere is determined
 - Negative lapse rate or inversion
 - ◆ In an unusual case, when the temperature of the environment (ambient air) increases with altitude then the lapse rate becomes *inverted* or *negative* from its normal state.
 - ◆ Negative lapse rate occurs under conditions, usually referred to as inversion, a state in which the warmer air lies over the colder air below. Such temperature inversion represents a highly **stable environment**.
 - *Radiation inversion*: it is a phenomenon occurring from unequal cooling rates for the earth and the air above the earth. (earth cools more rapidly and more quickly than air above it.). This type of phenomenon is observed more in winter nights.
 - *Subsidence inversion*: it is associated with a high-pressure system, and is caused by the characteristic sinking or subsiding motion of air in a high-pressure area surrounded by low pressure area (anti-cyclone). This inversion may be more dangerous than the radiation inversion, and may occur at modest altitudes and may often remain for several days.
 - ◆ Sometimes, both the radiation as well subsidence inversions may occur simultaneously, causing what is known as double inversion.

ELR > ALR Unstable	Looping plume 	Rising parcel of air will always remain warmer than the surrounding environment. As environment is getting cooler more quickly than the rising parcel. So warmer lighter air will continue to lift up. Dispersion of pollutant is heavy. The prevailing ELR in such condition, is known as super adiabatic lapse rate, as it is more than ALR.
ELR < ALR Stable	Coning plume	In this condition is ELR is called sub-adiabatic lapse rate, the environment is called stable.

		Plume shape is vertically symmetrical about the plume line, and reaches the ground at distance greater than looping plume.
ELR=ALR Neutral	Neutral plume 	This plume rises vertically upward. This occurs when ELR is equal to adiabatic lapse rate. The upward lifting of plume will continue till the air density becomes similar to that of the plume itself.
Temp increases above <i>Inversion</i>	Fanning plume 	Negative lapse rate occurs under conditions, usually referred to as <i>inversion</i> , a state in which the warmer air lies over the colder air below. Such temperature inversions represent a highly stable environment.
Lofting 	Fumigating 	Trapping 

d) Control of particulate pollutants in Industries

- Gravitational settling chambers
 - ◆ Size $\geq 50\mu\text{m}$, $\eta < 50\%$
 - ◆ These are simple to design and maintain, there is *low pressure loss*. But requires larger space and collection efficiency is low. Only larger sized particles are separated out.
 - ◆ The emitted smoke when pass through settling chamber, drop some of their larger sized particles in the chamber, under stokes' law.
- Centrifugal collectors including cyclone collectors and dynamic precipitators
 - ◆ Size = $5\text{-}25\mu\text{m}$, $\eta = 50\text{-}90\%$
 - ◆ It is relatively inexpensive and simple in design; requires less floor area; ensures dry continuous disposal of collected dusts with low to moderate pressure loss.
 - ◆ It can handle large volume of gases at temperature up to 90°C .
 - ◆ These are widely used in industries producing large quantity of gas containing larger sized particles, like *cement and fertilizer plants, petroleum refineries, asphalt mixing plants, grain mills, cotton gins* etc.
 - ◆ But these require much head room, collection efficiency is low for smaller particles and is quite sensitive to variable dust loading and flow rates.
 - ◆ A **cyclone collector** is a specially designed closed chamber, in which the velocity of the inlet gas is transformed into spinning vortex, and the particles from the gas are thrown out under the centrifugal force.
 - ◆ A **dynamic precipitator** imparts centrifugal force to the entering gas with the help of rotating vanes, and is about 7 times more efficient than an ordinary cyclone. They are widely used in ceramics, food and pharmaceutical, and wood working industries.
- Wet scrubbers

Spray towers	Wet cyclone scrubber	Venture-scrubbers
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Size >10µm, η < 80%	Size > 2.5µm, η < 80%	Size > 0.5µm, η < 99%
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- ◆ Spray tower and venture scrubber can be made to *remove gaseous pollutants along with particulate matter*. Hot gases can be cooled down, corrosive gases can be recovered and neutralized.
- ◆ A lot of waste water needing disposal may be produced, maintenance cost is high when corrosive materials are collected. Wet outlet gases cannot rise high from the stack. Poses freezing problem in cold countries, plume may be sometimes visible in sky due to the presence of water vapour.
- ◆ In these devices, the flue gas is made to push up against a down falling water current. The particulate matter mixes up with water droplets and thus falls down and get removed.
- ◆ Water solution, when replaced with other aqueous chemical solutions like lime, potassium carbonate, slurry of MnO and MgO etc. do help in removing gaseous pollutants also from the flue gases.
- Electrostatic precipitators
 - ◆ Size > 1µm, η = 95-99% $\eta = 1 - e^{-\frac{A_p v}{Q}}$
 - ◆ Particles may be collected wet or dry with good efficiency, even small particles can be removed. Maintenance is nominal, unless corrosive and adhesive materials are present in flue gases. They have few moving parts and can be operated at high temperatures up to 300-450°C
 - ◆ Higher initial costs. Sensitive to variable dust loading and flow rates. They use high voltage and hence may pose risk to personal safety of staff. Collection efficiency reduces with time.
 - ◆ In electrostatic precipitators, *the flue gas is made to pass through a highly ionized zone, where the particles get electrically charged and are separated out from the gas, with the help of electrostatic forces in the powerful electric field.*
 - ◆ They are widely used in thermal power plants, pulp and paper industries, mining and metallurgical industries, iron and steel plants, chemical industries etc.
- Fabric filters
 - ◆ Size >1µm, η >99%
 - ◆ Fabric filters can give high efficiency and can even remove very small particles in dry state. Performance decrease becomes visible, giving pre-warning.
 - ◆ High temperature gases need to be cooled to the range 100-450°C, within which, the filters are stable.
 - ◆ Flue gases must be dry, as otherwise, there is a risk of condensation inside the filter, which can cause clogging. The fabric is liable to chemical attack.
 - ◆ In such system flue gas is allowed to pass through a woven or felted fabric, which filters out the particulate matter and allow the gas to pass. small particles are retained on the fabric, initially through interception and electrostatic attraction and later on when a dust mat is formed, the fabric starts collecting particles more efficiently.

e) Effective height of stack (MAINS)

- Effective height $h_e = H + \Delta h$, actual height and plum rise
- Holland's equation

$$\Delta h(m) = \frac{v_s d}{u} \left[1.5 + 2.68 \times 10^{-3} P d \left(\frac{T_s - T_a}{T_s} \right) \right]$$

v_s is stack gas velocity m/sec

d diameter of stack m

u wind velocity m/sec

P atmospheric pressure in milli-bars

T_s stack gas temperature in K

T_a air temperature in K

f) Effect on air pollution on

- Plants:
 - ◆ Concentration of fluorine in excess of 0.3µg/m³ causes *phyto-toxicological* effects on plants.

- ◆ Pollutants clog stomata of leaf, reducing the intake of CO₂, which affects photosynthesis, leading to slow growth rate to total death of plants.
- ◆ Plants also absorb heavy metals like arsenic, lead, mercury, cadmium etc.; which prove very harmful to cattle and animals grazing on these vegetations.
- Animals:
 - ◆ When animal eat contaminated plant, grasses, fodder and other vegetation, they have adverse health effects like fluorosis, arsenic poisoning, lead poisoning.
- Buildings:
 - ◆ Air pollutants have deteriorating effects on metallic surfaces, glass surfaces, painted surfaces, building stones, rubber surfaces etc. along with damaging paper and fabric.
 - ◆ Oxides of Sulphur and nitrogen react with water vapour to form acidic fumes, which is highly corrosive.
- g) High volume sampler (MAINS)
 - High and low volume air samplers are instruments used to collect samples of air particles. The difference between high and low volume air samplers is the amount of air sampled. High volume air samplers typically sample more than 1500 cubic metres (m³) of air over a 24-hour period, while low volume air samplers draw through only 24m³ of air, or less.
 - High volume sampler is used for total suspended particulate matter (TSP) monitoring, which measures the total amount of particles suspended in the atmosphere. These TSP samples are also used to determine the levels of chemical elements and compounds in the particles which may pose a risk to human health.
 - The high volume air sampler draws a large known volume of air through a pre-weighed filter for 24 hours. After sampling, the filter is re-weighed and the difference in filter weight is the collected particulate matter mass. Dividing the mass by the volume of air sampled gives the concentration of TSP.
 - If required, the particulate matter retained on the filter is analysed to determine the concentration of pollutants, such as lead or other metals.

V. Noise pollution

a) Definition

- Noise can be defined as that unwanted sound pollutant, which produce undesirable physiological and psychological effects in an individual, by interfering with one's social activities like work, rest, recreation, sleep, etc.
- Effects:
 - ◆ Noise induced annoyance
 - ◆ Noise induced diseases: *anxiety, tenseness, nervousness, headaches, fatigue, nausea, insomnia, high blood pressure, high pulse rate, greater perspiration, gastric secretions.*
 - ◆ Sleeplessness
 - ◆ Communication interference
 - ◆ Noise induced hearing loss
 - ◆ Effect of noise on wild life: animals become dull and inactive during noisy conditions. Migratory birds stop resting in habitats close to noisy cities. They may even leave noisy habitats to move to calmer places, such change of habitat may sometimes alter their food habits, health and mating behaviour, bringing about environmental imbalances.
- Sources
 - ◆ Traffic: The amount and type of noise produced depends upon the type of aircraft or automobile used for the traffic.
 - ◆ Industries: noise is by-product of industry; its intensity and nature depend upon the type of the industry.

- ◆ Several other human activities, such as blaring of loudspeakers and sirens, shouting of hawkers, playing of children, general life and activity, ringing of temple and church bells etc. do produce noises.
- Noise abatement and control
 - ◆ New Laws need to made and implemented for control of noise pollution by vehicles, industries and general public.
 - ◆ By using proper town planning techniques, ensuring construction of houses and offices away from major sources of noise. Proper segregation, zoning and separation of residential complexes from the commercial and industrial ones.
 - ◆ Raising of obstructions and barriers in between the noise source and residents, may considerably reduce the noise levels.
 - ◆ Raising of thick and high vegetation and tree growing along sides of roads and railway lines.

b) Characteristics of sound and its measurement

- The time between successive peaks or troughs of oscillation is called **period (P)**. Inverse of period which represents the number of times a peak arrives in one second is called **frequency (f)**.

$$P = \frac{1}{f}$$

- Distance between successive peaks or troughs is called **wavelength (λ)**. Which is related as

$$\lambda = c \cdot \frac{1}{f}$$

c is velocity of sound wave.

- The **amplitude (A)** of wave is the height of peak sound pressure measured above or below the zero-pressure line. The **equivalent pressure** of a sine wave is represented by root mean square pressure (p_{rms})

$$p_{rms} = \sqrt{\frac{1}{T} \int_0^T p_{(t)}^2 dt}$$

- **Power of sound (W)**: the *energy transmitted by a sound wave in the direction of its propagation is thus, defined as its power*, and is represented in watts in SI units
- **Sound intensity (I)**: it is defined as the *sound power averaged over the time*, per unit area normal to the direction of propagation of the sound wave. Unit watt/m²

$$\diamond I = \frac{W}{a}$$

$$\diamond I = \frac{p_{rms}^2}{\rho c}$$

c) Levels of Noise

- The sound pressure of the faintest sound that can be heard by a normal individual is 20μPa. on the other hand, the loudest sound produced by a Saturn rocket at the lift off stage is about 200Pa.

- ◆ Range of human hearing 🦻 (20μPa, 200Pa)

- Level of noise of any given sound pressure is always measured w.r.t. standard reference sound pressure.

$$\diamond L = \log_{10} \frac{I}{I_o} \text{ (bels)}$$

- ◆ Since bels turns out to be a rather large unit, a smaller unit **decibel** is used.

$$\diamond \text{Sound intensity } I_o = 10^{-12} \text{ W/m}^2$$

$$L \text{ (dB)} = 10 \log_{10} \frac{I}{I_o} = 10 \log_{10} \frac{I}{10^{-12}}$$

$$L \text{ (dB)} = 10 \log_{10} \left(\frac{p_{rms}}{20\mu Pa} \right)^2 = 20 \log_{10} \left(\frac{p_{rms}}{20\mu Pa} \right)$$

- ◆ An increase of 20dB in sound pressure level will correspond to the sound pressure or loudness of sound increasing by 10 times.

- ♦ One dB is the faintest sound which can be perceived by human ear and the maximum sound which can be tolerated is 180dB.
- Addition of such sound levels cannot be done by simple arithmetic addition, because log scale is involved.

$$♦ \quad 50dB + 50dB = 53 dB$$

d) Frequency

- Although, sound pressure level, gives a physical measurement of sound, yet it cannot be taken at face value as a perfect indication of loudness, because it does not account for the frequency of sound which has a lot to do with how loud a noise sounds to human ears.
- **Frequency of sound** is defined as the number of vibrations per unit time, and its unit is **hertz** (Hz). Although human ear can hear sound waves in the frequency range of 10 to 20,000 Hz, but human ear is more sensitive to sounds of middle frequency.
- Hence, while measuring the loudness of a sound, electronic filtering circuits (**weighting networks**) are built into the sound pressure measuring meters, which filter out certain frequencies.
- Three types of filtering circuits A, B, and C types are often used in sound meters, but **A network** is generally used in our day to day sound measurements.

e) Averaging sound pressure levels

- The average value of various recorded sound pressure levels at a particular place over a given period cannot be computed by simple averaging due to log scale involved in their values. So the following equation is used:

$$\bar{L}_p = 20 \log_{10} \frac{1}{N} \sum 10^{\frac{L_n}{20}}$$

- for objective use max value inside addition

f) Noise rating systems

- A noise may consist of different types of sounds with different pressure levels operating for different time intervals. The frequencies of these sounds may also vary. The combined resultant noise will in fact be responsible for determining the human response and degree of annoyance caused by it. The combined impact of different sound pressures lasting for different periods is therefore attempted to be worked out by using some statistical measures, such as L_N and L_{eq} systems.
- **The L_N concept:**
 - ♦ The parameter L_N is a statistical measure indicating **how frequently a particular sound level is exceeded**.
 - ♦ The value of L_N will represent the sound pressure level that will exceed for N% of the gauging time.
 - ♦ To find L_N arrange the noise values in decreasing order and chosen.
- **The L_{eq} concept:**
 - ♦ L_{eq} is the statistical value of sound pressure level that can be equated to any fluctuating noise level.
 - ♦ Example: a sound of 80dB lasting for 10 minutes, followed by a sound of 60dB lasting for the next 80 minutes, and then followed by a sound of 100dB for the next 5 minutes, will compose a fluctuating noise level, which can be represented by a certain dB value which is indicative of producing the same effect over the entire time period of $10+80+5=95$ minutes as the original fluctuating noise.
 - ♦ This value is called the **equivalent continuous equal energy level** or equivalent noise level.
 - ♦ L_{eq} is defined as the constant noise level, which over a given time expands the same amount of energy, as is expanded by the fluctuating level over the same time.

$$L_{eq} = 10 \log \Sigma (10^{L_i/10} \cdot t_i)$$

- t_i is fraction of gauging time

g) Variation with distance

$$L_2 = L_1 - 20 \log \frac{r_2}{r_1}$$

h) Ambient air quality standards in respect of noise

Area code	Category of area	Limits in $dB(A)$ L_{eq}	
		Day time (6-10)	Night time (10-6)
A	Industrial area	75	70
B	Commercial area	65	55
C	Residential area	55	45
D	Silence area	50	40